2.8 ON-BOARD DECEPTIVE ECM

Employment of jamming signals that displace the target position perceived by a threat (victim) radar from the true location using a jammer located on the target aircraft constitutes on-board deceptive ECM. The techniques may degrade angle, range, or Doppler track. With the latter two, there is no angle deception, which means that the target could be intercepted if some cooperative action were not taken. Usually, the range or Doppler gate is swept off of the target return and then dropped. When the jam signal is dropped, the aircraft makes an evasive maneuver so that the missile will not be able to recover and make the intercept once the aircraft is reacquired.

Typically, deceptive jamming is used after a threat has acquired and locked on to the target and is in the process of firing ordnance at it. Deceptive jamming may require detailed technical knowledge of the threat system so that specific signal processing characteristics can be exploited.

ESAMS 2.7 models the following on-board deceptive ECM techniques listed below.

1. Amplitude Modulation (SRM, TWS Jam, SSW, Wobbulation)
2. Terrain Bounce (TB)
3. Cross-eye (CE)
4. Velocity gate pulloff (VGPO)
5. Range gate pulloff (RGPO)
6. Coordinated Range and Velocity gate pulloff (RVGPO)

A brief discussion of each of these is provided in the following paragraphs.

Amplitude Modulation (AM)

This technique is designed to induce angle track errors and is referred to by names such as swept rectangular modulation (SRM), swept square wave (SSW), TWS jamming, and wobbulation. Under non-jamming conditions, the amplitude of the target return will be greatest when the antenna is pointed directly at the target, and the antenna gain is also greatest. AM techniques put jamming energy at a significantly higher level than the target signal return when the scanning radar is not pointed directly at the target. For a trough-type TWS radar, jamming energy will be received by one side or the other of the antenna as it scans back and forth across the target. This results in a signal that deceives the angle discriminator because the strongest (i.e., jamming) signal is at an angle opposite that of the target. For AM techniques to work effectively, the jam energy must be synchronized to match the victim radar’s scan rate, or be on a harmonic. Otherwise, in a worst case, the missile could be directed back and forth across the target aircraft. Although the specific waveforms in this category may have some unique features depending upon the victim radar, they all modulate the jammer amplitude profile.

Terrain Bounce (TB)

This deceptive technique generates a false target by bouncing a repeater jamming signal off of the terrain, which then reflects it into the seeker receiver. The interaction between an aircraft employing TB and a semi-active missile, is illustrated in Figure 2.8-1. The false target is generated in the seeker processor appearing to be at the vector along R_3, and the missile will typically track on the radar centroid between the false and actual targets.

The effectiveness of the technique is dependent upon the relative magnitudes of the direct signal ($J_d + S_d$) and the terrain-bounced signal ($J_r + S_r$) received at the missile seeker where:

J_d = jammer leakage
S_d = reflected illuminator signal
J_r = jammer decoy point signal
S_r = reflected illuminator multipath signal.

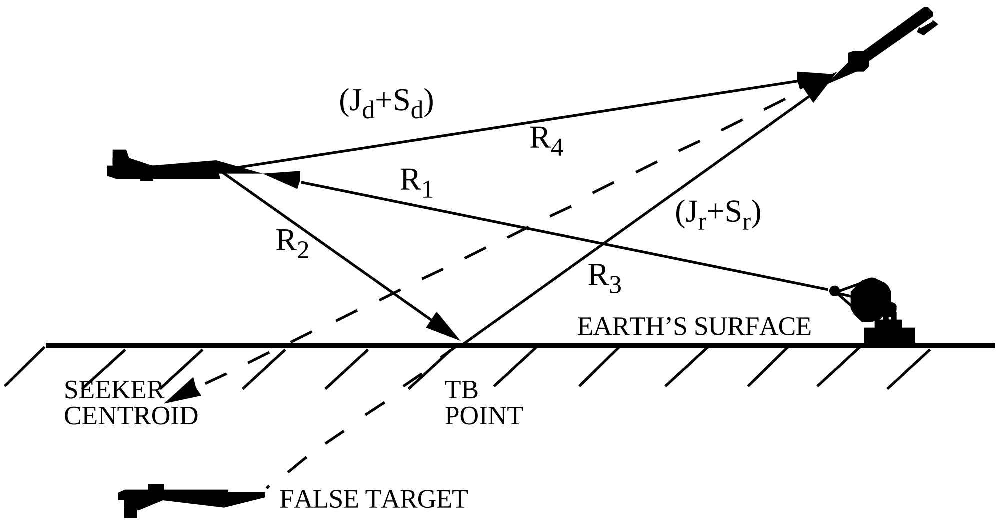


FIGURE 2.8-1. Terrain Bounce Geometry.

Cross-eye Jamming

Monopulse tracking radars attempt to align their antenna normal to the incoming signal wavefront. The tracking angle to the target is based on this alignment. If, for some reason, the wavefront has been distorted, then tracking errors will develop. The purpose cross-eye jamming technique is to develop such a distortion.

The basic concept of cross-eye is that with two radiators or reflectors, there are certain geometries in which the wavefront can be distorted. These are the directions in which the magnitudes of the two energy sources are equal, but their phases differ by 180°. Thus, there is total cancellation, and, instead of a spherical propagation, there is a discontinuity.

Figure 2.8-3 is a simplified illustration of how cross-eye jamming works. In the unjammed case on the left, the wave fronts arrive parallel to an antenna aligned in the direction of the target resulting in an in-phase electrical field distribution and the Fourier transform resulting in the normal antenna pattern. In the cross-eye jammed case on the right, the two radiating jammer antennas are radiating at equal strength, but 180° out of phase with each other. This results in a distortion of the electrical field with the Fourier transform having a null at the center, and the apparent target direction shifted to the left.

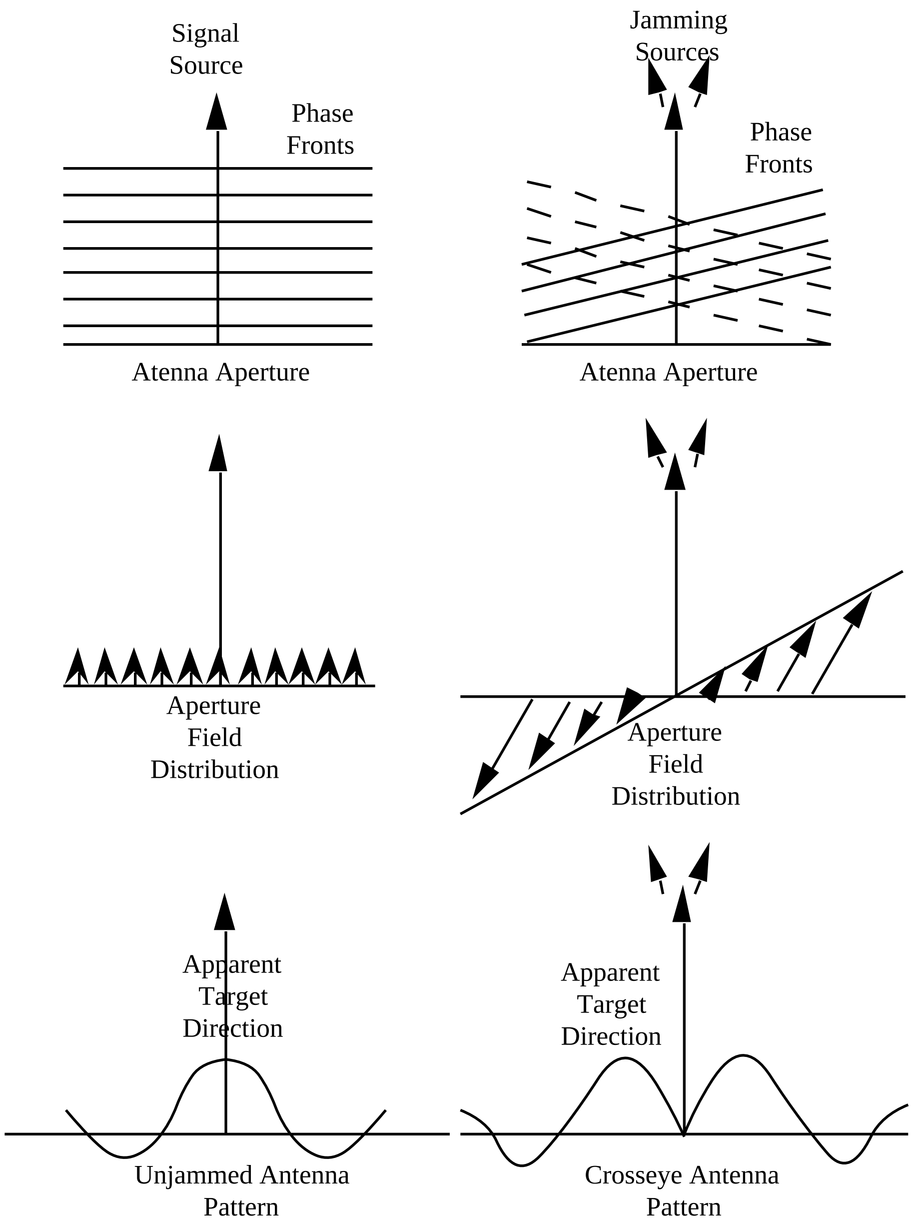


FIGURE 2.8-2. Simplified Example of Cross-eye Jamming Effects.

Gate Pulloff (VGPO, RGPO, RVGPO)

Gate stealing involves pulling the velocity gate, the range gate, or both off of the target and then dropping the jam signal. If the procedure is successful, the radar goes into a coast mode while attempting re-acquisition. During this period, a crisp target maneuver may be effective in degrading missile intercept capability.

The velocity gate is pulled off the target by gradually changing the Doppler frequency of the jamming signal. The range gate is pulled off in a similar manner by gradually adding a time delay to the jamming signal increasing the apparent range of the target from the radar. The jamming signal is at a higher power than the return skin signal from the target, and overpowers the target return causing the jamming signal to be tracked.

2.8.1 Functional Element Design Requirements

This section contains the design requirements necessary to fully implement the deceptive on-board ECM simulation.

a. ESAMS will simulate the jamming signals introduced into threat radar tracking radars by amplitude modulation techniques (SRM, TWS Jam, SSW, Wobbulation).

   ESAMS will calculate the geometry of the engagement including position of the SAM radars and missile seekers in the engagement. The radar signal from the illuminating radar to the jammer platform will be calculated using standard radar equations. The signal out from the jammer using table specified values characterizing the sweep type, ramp times, offset frequencies, center frequencies, duty cycles, and jammer power will be calculated. The signal over time received at the victim radar from the jammer will be calculated. The calculations will include gain patterns for jammer and SAM transmit and receive antennas. The complex voltages over time from the amplitude modulation jammer will be calculated for the radar receiver's sum, azimuth difference, and elevation difference channels using standard radar equation derivations. These values will be passed on to be used in the signal processing functional area in ESAMS.

b. ESAMS will simulate the jamming signals introduced into threat missile seekers by terrain bounce jamming.

   ESAMS will calculate the geometries of the jammer aircraft, ground radar illuminators, and missile seekers. The radar signal from the illuminating radar to the jammer platform will be calculated using standard radar equations, the signal out from the jammer using table specified values will be calculated, and the signal received at the missile seeker from the jammer will be calculated. The signal to the missile seeker will include the reflectivity of the terrain or water including the dielectric coefficient and scattering from roughness of the surface. The calculations will include gain patterns for jammer receive and transmit antennas, and the direct signal from the jammer to the victim radar as well as the bounced signal from the jammer to the terrain and then to the target will be calculated. The complex voltages to the receiver’s sum, azimuth difference and elevation difference channels will be calculated using standard radar equations. These will be passed on to the used in the signal processing areas of ESAMS.

c. ESAMS will simulate the jamming signals introduced into monopulse tracking radars by cross-eye jamming.

   ESAMS will calculate the geometry of the jammer aircraft, the antenna locations on the aircraft, and the tracking radar. The radar signal from the illuminator to the jammer platform will be calculated using standard radar equations, the signal out from the jammer’s two antennas using table specified values characterizing the phase shifting of the cross-eye jamming will be calculated, and the signal received at the tracking radar from the jammer will be calculated. The calculations will include gain patterns for jammer and jammed radar receive and transmit antennas. The complex voltages to the receiver's sum, azimuth difference and elevation difference channels will be calculated using standard radar equations. These will be passed on to the used in the signal processing areas of ESAMS.

d. ESAMS will simulate the jamming signals introduced into tracking radars by velocity gate, range gate, and combined velocity and range gate pull off jammers.

ESAMS will calculate the geometry of the jammer aircraft, ground radar illuminators and receivers, and missile seekers. The radar signal from the illuminating radar received at the jammer platform will be calculated using standard radar equations. The signal out from the jammer using table specified values defining the time phased jamming strength, Doppler shifts, phase shifts, relative polarization, relative pulse width, and time shifts in signal retransmission to draw off the velocity and/or range gates will be calculated. The signal received from the jammer at the tracking radar will be calculated. The calculations will include gain patterns for jammer and jammed radar receive and transmit antennas. The complex voltages to the receiver's sum, azimuth difference and elevation difference channels will be calculated using standard radar equations. These will be passed on to the used in the signal processing areas of ESAMS.

2.8.2 Functional Element Design Approach

This section describes the design approach (equations, algorithms, and methodology) implementing the design requirements of the previous section. Deceptive ECM can affect both target acquisition and target tracking of ground radars, and the tracking by missile seekers. Deceptive ECM is not used against fuzes in ESAMS.

Most of the basic design elements for on-board deceptive ECM have been defined in section 2.5, on-board noise ECM. The basic geometry, Doppler, phase, power and complex voltage calculations are identical for deceptive jamming as for noise jamming. The major new areas that are defined here are amplitude modulation waveform calculation to determine whether the jammer is transmitting a jamming signal at a given time, terrain bounce geometry and voltage calculations, cross-eye waveform definition, and VGPO, RGPO, and RVGPO waveform definition.

Design Element 8-1: Terrain Bounce Jammer Leakage

Jammer leakage in the direction of the missile seeker is caused by the fact that some of the power in terrain bounce jamming goes to the ground and then to the missile seeker, but some signal will go directly from the jammer to the missile seeker. The leakage signal can actually aid the missile in intercepting the target aircraft. The direct path complex voltages are calculated and put on the signal bus for use by the processor during the standard jammer voltage calculation using the jammer gain in the direction of the seeker and the equations described in FE 2.5. These equations are not be repeated here.

Design Element 8-2: Calculation of Amplitude Modulation Jammer on and off Times

This portion of the design addresses the calculation of the amplitude modulation frequency of the jammer. Amplitude modulation can be entered into ESAMS in two ways; a time stepped look-up table, or calculated within ESAMS. When the table is used, ESAMS simply loops through the waveform generators using the time stepped tables since they specify whether the jammer is transmitting or not and what the appropriate jammer power level (full power or zero) should be. When calculating the modulation, ESAMS loops through calculating time stepped jammer on-off periods until the time of interest is calculated. The jammer on-off status is determined and a flag set and passed on to read the appropriate jammer power.

ESAMS calculates square-wave modulation, also known as “wobbulation”. It is much like the pulse modulation of the transmitted energy of a pulsed radar; when the square wave is at its high value the jammer transmitter radiates energy through the antenna, and when the square wave is at its low value the jammer does not radiate. The first two major characteristics of the modulation are then the analogue of the pulse repetition frequency (PRF)—the frequency at which the modulation switches from low to high—and the duty cycle—the fraction of a pulse repetition interval (PRI=1/PRF) during which the modulation is at the high level. The duty cycle is thus the ratio of pulse width to PRI.

A major difference between the usual radar pulse modulation and the AM waveform of ECM is that the PRF in the ECM waveform may itself be time-varying. The simplest time variation, and that which is modeled in ESAMS is that of a linear sweep of frequency. For this ECM waveform,

$$f_{AM}(t) = f_{start} + f' \times t \qquad [2.8\text{-}2]$$

where f_{start} is the starting (reference) frequency and f’ is the rate of change. In this case, the PRI can be found as follows. In analogy with the sinusoidal waveform, $\sin(2\pi f(t)t)$, the waveform begins a new PRI whenever the phase, $2\pi f(t)t$, has increased by 2π. The beginning of the n-th PRI is then at time $t=t_n$, where t_n is given by the condition

$$f(t_n)t_n = n, \qquad n = 0, 1, 2, \ldots \; . \qquad [2.8\text{-}3]$$

For the linear frequency sweep of equation [2.8-2] this yields a quadratic equation in t_n:

$$f' t_n^2 + f_{start} t_n - n = 0 \; , \qquad [2.8\text{-}4]$$

with solution

$$t_n = -\left(\frac{f_{start}}{2f'}\right) \pm \sqrt{\left(\frac{f_{start}}{2f'}\right)^2 + \frac{n}{f'}} \; . \qquad [2.8\text{-}5]$$

The sign in equation [2.8-5] must be chosen to make t_n positive.

The AM waveform can be characterized by four parameters. These four parameters define the top and bottom of the pulse repetition intervals that will be used by the jammer, how long the jammer takes to go through a complete cycle of frequencies, and for what fraction of the time (duty cycle) the jammer will be on for each pulse time. The parameters are:

T_{RS} = The frequency sweep ("scan") repeat period
f_{ctr} = The center frequency of the frequency of the scan
Δf = The maximum excursion of the swept frequency away from f_{ctr}
d_{cycle} = Duty cycle. The fraction of a PRI that the jammer radiates.

ESAMS calculates one of three types of amplitude modulation which is user defined by setting SWPTYPE: 1-up sweep, 2-down sweep, 3-saw sweep. The following equations calculate the slope and starting frequency of up sweep AM:

$$f' = \frac{2\Delta f}{T_{FS}} \tag{2.8-6}$$

$$f_{start} = f_{ctr} - \Delta f \tag{2.8-7}$$

The following equations calculate the slope and starting frequency of down sweep AM:

$$f' = \frac{-2\Delta f}{T_{FS}} \tag{2.8-8}$$

$$f_{start} = f_{ctr} + \Delta f \tag{2.8-9}$$

The slope and starting frequency of saw sweep AM has two phases. During the upsweep portion of the sweep the slope and starting frequency are calculated:

$$f' = \frac{-2\Delta f}{T_{FS}/2} \tag{2.8-10}$$

$$f_{start} = f_{ctr} - \Delta f \tag{2.8-11}$$

When one half of the cycle had been completed (the upsweep portion) the slope and starting frequency are calculated:

$$f' = \frac{-2\Delta f}{T_{FS}/2} \tag{2.8-12}$$

$$f_{start} = f_{ctr} + \Delta f \tag{2.8-13}$$

With the four parameters T_{RS},f_{ctr},Δf, and d_{cycle} one can build the three waveform frequency variations $f_{AM}(t)$ shown in Figure 2.8-4. The first waveform frequency shown corresponds to a low value of f_{start} and a positive slope f'. The second corresponds to a high value of f_{start} and a negative f'. For the third waveform frequency, one could as easily start high or start low. The convention used here is starting low; then the slope is positive to midway through the revisit time, at which f_{start} switches high and f' changes sign for the rest of the revisit period. All three waveforms described by the $f_{AM}(t)$ in Figure 2.8-4 are provided for by an option switch which calculates the frequency time steps described below for each of the three cases. The same discriminant is used for all cases and is calculated:

$$D = \sqrt{\left(\frac{f_{start}}{2f'}\right)^2 + \frac{n}{f'}} \qquad [2.8\text{-}14]$$

For up sweep from equation 2.8-5 the start of the next time period is calculated:

$$T_{on} = \frac{-f_{start}}{2f'} + D \qquad [2.8\text{-}15]$$

For down sweep from equations 2.8-5 the start of the next time period is calculated:

$$T_{on} = \frac{-f_{start}}{2f'} - D \qquad [2.8\text{-}16]$$

Where:

n	=	the number of the pulse in the frequency sweep
T_{on}	=	the time the jamming pulse turns on

The time off is then calculated by adding the time the jammer is on to the jam start time. The length of time the jammer is on is the duty cycle times the duration of the jam cycle (PRI).

$$T_{off} = T_{on} + \frac{d_{cycle}}{f_{start} + (f' T_{on})} \qquad [2.8\text{-}17]$$

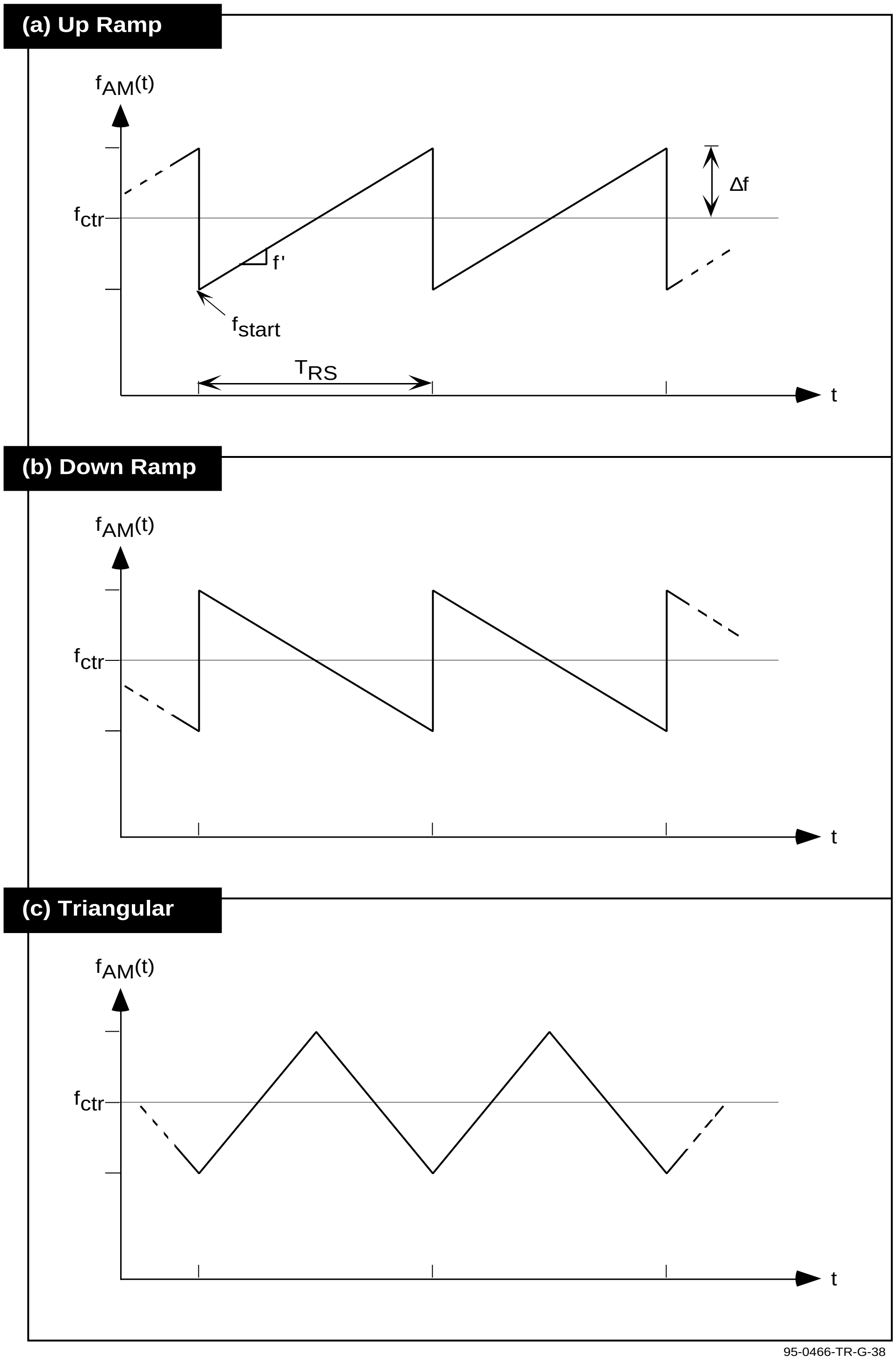


FIGURE 2.8-3. Linear Frequency Sweeps for Amplitude Modulation ECM.

Design Element 8-3: Complex Voltage from Amplitude Modulation Jamming

Once the on/off times for the amplitude modulated jamming is known, the complex voltage for the sum, azimuth difference and elevation difference channels is then calculated for the time of interest as described in FE 2.5. The complex voltages are put on the bus and passed to the signal processing FE.

Design Element 8-4: Terrain Bounce Geometry

To simulate the effects of terrain bounce jamming, the geometry of the apparent target signal (the decoy) must be calculated. The actual target, and missile x, y, and z positions are known. The decoy x, y, and z position, and range and angle to the missile and x, y, and z position and range to the target must be calculated.

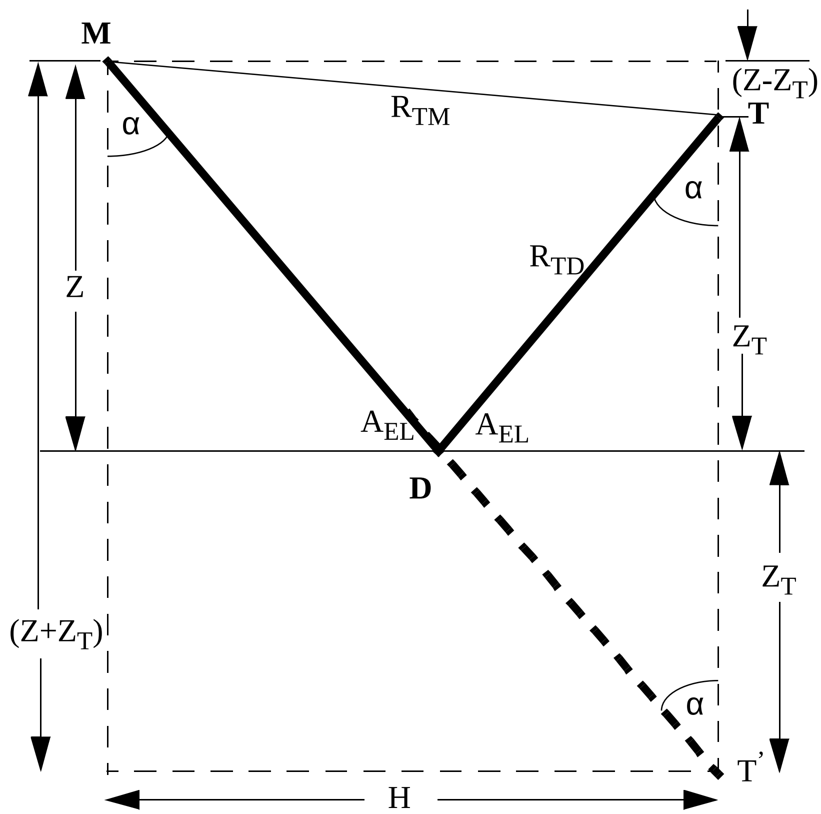


FIGURE 2.8-4. Terrain Bounce Geometry.

Figure 2.8-5 shows the relationships between the target, missile and ground where:

T	=	the target aircraft position
M	=	the missile position
D	=	the decoy position
Z_t	=	the height of the target
Z	=	the height of the missile

H	=	the range between the missile and target in the xy plane
R_{TM}	=	the slant range between the target and missile
R_{TD}	=	the slant range to the decoy target

Angle α as shown satisfies following:

$$\tan(\alpha) = \frac{H}{(Z + Z_T)} = \frac{\sqrt{1 - \cos^2\alpha}}{\cos\alpha} \qquad [2.8\text{-}18]$$

and

$$\cos(\alpha) = \frac{Z_T}{R_{TD}}. \qquad [2.8\text{-}19]$$

Horizontal range between missile and target, H, satisfies:

$$H = \sqrt{R_{TM}^2 - (Z - Z_T)^2} \qquad [2.8\text{-}20]$$

Substitute for H and $\cos(\alpha)$ in 2.8-18:

$$\frac{\sqrt{R_{TM}^2 - (Z - Z_T)^2}}{(Z + Z_T)} = \frac{\sqrt{1 - (Z_T/R_{TD})^2}}{Z_T/R_{TD}} \qquad [2.8\text{-}21]$$

Solve for R_{TD}:

$$\left(\frac{Z_T}{R_{TD}}\right)^2 [R_{TM}^2 - (Z - Z_T)^2] = (Z + Z_T)^2 - \left(\frac{Z_T}{R_{TD}}\right)^2 (Z + Z_T)^2$$

$$\left(\frac{Z_T}{R_{TD}}\right)^2 [R_{TM}^2 - (Z - Z_T)^2 + (Z + Z_T)^2] = Z_T^2 \left(1 + \frac{Z}{Z_T}\right)^2 \qquad [2.8\text{-}22]$$

$$R_{TD}^2 = \frac{R_{TM}^2 + 4Z\,Z_T}{(1 + Z/Z_T)^2} \qquad [2.8\text{-}23]$$

And R_{TD} is calculated.

$$R_{TD} = \frac{\sqrt{R_{TM}^2 + 4ZZ_T}}{1 + Z/Z_T} \qquad [2.8\text{-}24]$$

The elevation angle, A_{EL}, to the target from the decoy (grazing angle) is then calculated:

$$A_{EL} = \sin^{-1}\left(\frac{Z_T}{R_{TD}}\right) \qquad [2.8\text{-}25]$$

The the decoy azimuth angle, A_{AZ}, from the target in the direction of the missile is:

$$A_{AZ} = \tan^{-1}\left(\frac{Y - Y_T}{X - X_T}\right) \quad , \qquad [2.8\text{-}26]$$

where:

X and Y= the x, y location of the missile
X_T and Y_T= the x, y location of the target.

The x, y, and z location of the decoy (X_D, Y_D, Z_D) is then calculated:

$$X_D = \sqrt{(R_{TD}^2 - Z_T^2)}\cos A_{AZ} + X_T \qquad [2.8\text{-}27]$$

$$Y_D = \sqrt{(R_{TD}^2 - Z_T^2)}\sin A_{AZ} + Y_T \qquad [2.8\text{-}28]$$

$$Z_D = 0 \qquad [2.8\text{-}29]$$

for zero terrain heights.

The decoy to target range in x, y, z is then calculated.

$$R_{TDX} = X_D - X_T \qquad [2.8\text{-}30]$$

$$R_{TDY} = Y_D - Y_T \qquad [2.8\text{-}31]$$

$$R_{TDZ} = Z_D - Z_T \qquad [2.8\text{-}32]$$

For non zero terrain heights (terrain height = T_H) the apparent decoy to target height is:

$$R_{TDZ} = T_H - Z_T \qquad [2.8\text{-}33]$$

and the target to decoy range and elevation angle are recalculated to account for the terrain elevation:

$$R_{TD} = \sqrt{R_{TDX}^2 + R_{TDY}^2 + R^2{}_{TDZ}} \qquad [2.8\text{-}34]$$

$$A_{EL} = \sin^{-1}\left(\frac{Z_T - T_H}{R_{TD}}\right) \qquad [2.8\text{-}35]$$

The missile to decoy x, y, z ranges (R_{MDX}, R_{MDY}, R_{MDZ}) and slant range (R_{MD}) are then calculated:

$$R_{MDX} = X_D - X \tag{2.8-36}$$

$$R_{MDY} = Y_D - Y \tag{2.8-37}$$

$$R_{MDZ} = Z_D - Z \tag{2.8-38}$$

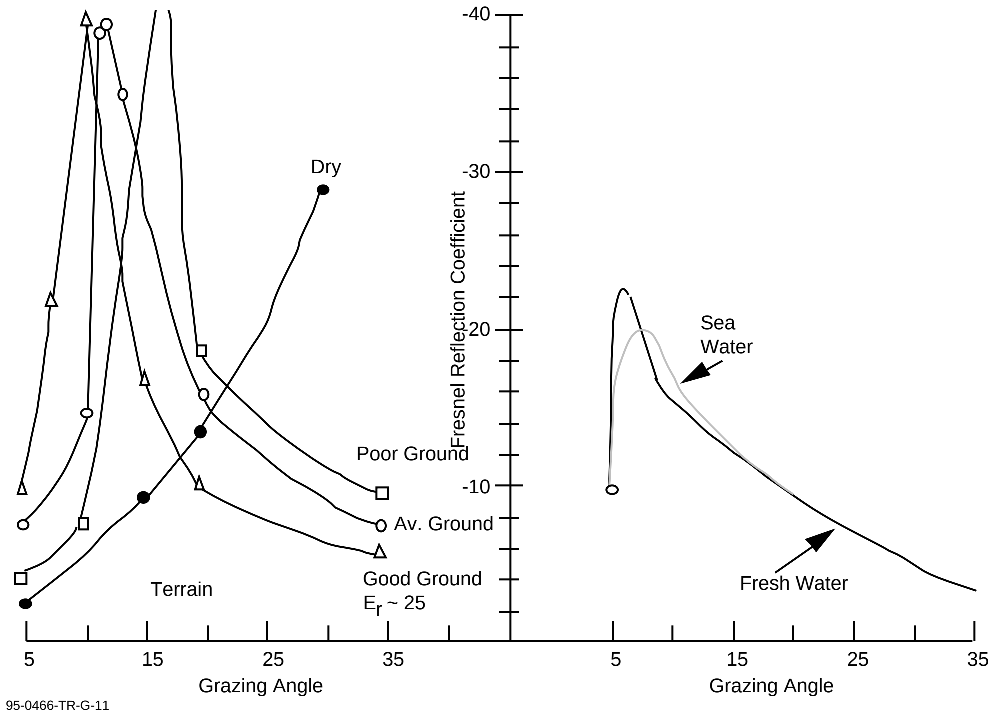
$$R_{MD} = \sqrt{R_{MDX}^2 + R_{MDY}^2 + R_{MDZ}^2} \tag{2.8-39}$$

Design Element 8-5: Power Calculations With Perfect Reflection

Power calculations at the receiver are first made without the effects of terrain, assuming perfect reflection of the jammer signal. The difference between power for terrain bounce jamming and direct path jamming is the difference in the gain of the jammer antenna to the decoy point and the gain of the missile seeker antenna to the decoy point, and the range from the jammer to the seeker used in the power calculation (R_{TD}+R_{MD}). The power calculations are included in FE-2.5 and will not be repeated here.

Design Element 8-6: Terrain Bounce Path Loss Calculations

A significant factor in a TB engagement is the *terrain reflectivity* and the scattering due to *terrain roughness*. These are characterized by the Fresnel reflection coefficient, specular scattering coefficient, and the spacial distribution coefficient (SDC). The Fresnel reflection coefficient is represented as a function of grazing angle for several types of terrain and water conditions. Figure 2.8-2 illustrates the magnitude of these coefficients for different types of terrain and water.



(UNCLASSIFIED)

FIGURE 2.8-5. Fresnel Reflection Coefficient.

For ground, the curves are valid from 500 MHz to 10 GHz. For water, the curves are valid only at 10 GHz, because the Fresnel coefficient varies substantially with frequency (see [30] for a more complete discussion). The Rayleigh scattering coefficient takes into account the reduction in specular reflection due to terrain roughness. It is a function of the RMS height of surface irregularities, the grazing angle, and the wavelength of the jamming.

A component of terrain roughness is captured by the SDC. As the terrain roughness increases, the reflected energy spreads out in a conical pattern about the specular angle, and less TB energy is received by the missile seeker. The SDC modeled in ESAMS is based on a theoretical development by Hughes Aircraft Company [31]. A comprehensive discussion of the terrain bounce jamming and the SDC is contained in the GRAM Analyst Manual [5].

The ESAMS terrain bounce jamming model ignores secondary signals such as multipath, and it simulates TBC effectiveness based on the target illumination signal (S_d), the jammer leakage in the direction of the missile (J_d), and the jamming signal reflected from the terrain (J_r). The equations of interest are the standard radar power calculations with specular and diffuse reflection factors included for the bounced signal:

$$J_d = \frac{P_J G_{Jd} G_{md} \lambda^2}{(4\pi)^2 R_4^2} \qquad [2.8\text{-}40]$$

$$S_d = \frac{P G G_{md} \lambda^2 \sigma}{(4\pi)^3 R_1^2 R_4^2} \qquad [2.8\text{-}41]$$

$$J_r = \text{Specular} + \text{Diffuse Reflection}$$

$$= \frac{P_J G_{Jr} G_{mr} \lambda^2}{(4\pi)^2 \left(R_2 + R_3\right)^2} \left|R(\psi)\right|^2 \left|F_c\right|^2$$

$$+ \frac{P_J G_{Jr} G_{mr} \lambda^2}{(4\pi)^3} \int \frac{\sigma^0 \, ds}{R_2^2 \, R_3^2} \left|R(\psi)\right|^2 \left|F_c^2 - 1\right| \qquad [2.8\text{-}42]$$

where:

PG	=	effective radiated power of target illuminator
P_J	=	jammer power
G_{Jr}	=	jammer antenna gain (r-reflected, d-direct)
G_{mr}	=	Seeker antenna gain (r-direction of reflection, d-direction of target)
σ	=	target RCS
σ^0	=	terrain scattering cross-section
$R(\psi)$	=	Fresnel reflection coefficient
F^2_c	=	RMS specular scattering coefficient.

The integral is solved with the aid of the Hughes SDC [31]. The GRAM Analyst Manual [ref. 5, Pgs. V-1 through V-11] discusses TB and references the fact that simplifications must be made to do the integration. Because the simplifications were unknown, only intuitive trends can be verified.

The Fresnel reflection coefficient and the Rayleigh scattering coefficient allow the energy lost through transmission into the terrain and scattering due to terrain roughness to be determined. ESAMS calculates the Fresnel scattering coefficient for vertically polarized radars only since most low flying semi-active seekers use vertical polarization. The following equation is used [32]:

$$R(\psi)_V = \frac{\varepsilon_c \sin\psi - \sqrt{\varepsilon_c - \cos^2\psi}}{\varepsilon_c \sin\psi + \sqrt{\varepsilon_c - \cos^2\psi}} \qquad [2.8\text{-}43]$$

where:

ε_c	=	$\varepsilon_r - j_{60}\lambda\sigma$
ε_r	=	dielectric constant
λ	=	wavelength
σ	=	conductivity

The Rayleigh scattering coefficient takes into account the reduction in specular reflection due to terrain roughness. The equation is [32]:

$$F_c = \exp\left[-\left(\frac{4\pi h_{rms} \sin\psi}{\lambda}\right)^2\right] \quad [2.8\text{-}44]$$

where:

h_{rms} = root-mean-square height of surface irregularities
ψ = grazing angle
λ = wavelength

The spatial distribution coefficient, C_{SD}, is now determined so that the diffuse reflection impact on seeker performance can be quantified. As discussed in section 2.8, the form used in ESAMS is [31]:

$$C_{SD} = \frac{\sigma_\theta \sigma_\varphi}{\sin\psi(\sigma_\theta^2 + 4\sigma_{a_2}{}^2)^{1/2}(\sigma_\varphi^2 + 4\sigma_{a_2}{}^2)^{1/2}} \quad [2.8\text{-}45]$$

where:

$$\sigma_\theta = \frac{0.41\theta_T\theta_R}{\left[\varphi_R^2 + \varphi_T^2\left(\frac{h_T}{h_R}\right)^2\right]^{1/2}} \quad [2.8\text{-}46]$$

$$\sigma_\varphi = \frac{0.42\varphi_T\varphi_R}{\left[\varphi_R^2 + \varphi_T^2\left(\frac{h_T}{h_R}\right)^2\right]^{1/2}} \quad [2.8\text{-}47]$$

and:

θ_T = 3dB elevation beamwidth of the transmitter
θ_R = 3dB elevation beamwidth of the receiver
φ_T = 3dB azimuth beamwidth of the transmitter
φ_R = 3dB azimuth beamwidth of the receiver
h_T = height of the transmitter
h_R = height of receiver
ψ = grazing angle

The total path loss is then calculated:

$$L = R(\psi)_V{}^2[F_c + C_{SD}(1 - F_c)] \quad [2.8\text{-}48]$$

Design Element 8-7: Phase, Doppler and Range Calculations

To calculate the complex voltages the phase information must be calculated. The complex phase angle is calculated:

$$\varphi = 2\pi \frac{\mathrm{mod}(R_{TS} + R_{TD} + R_{DM} + R_{PD}, \lambda)}{\lambda} \qquad [2.8\text{-}49]$$

where:

R_{TS} = range from the radar site to the target with the jammer
R_{TD} = range from the target to the decoy
R_{DM} = range from the decoy to the missile
R_{PD} = the jammer phase delay range

The decoy to missile relative velocity components are given by:

$$V_{DMX} = V_{DX} - V_{MX} \qquad [2.8\text{-}50]$$

$$V_{DMY} = V_{DY} - V_{MY} \qquad [2.8\text{-}51]$$

$$V_{DMZ} = V_{DZ} - V_{MZ} \qquad [2.8\text{-}52]$$

where:

$V_{DMX,Y,Z}$ = the x, y, and z decoy to missile relative velocity components.
$V_{DX,Y,Z}$ = the x, y, and z decoy velocity components.
$V_{MX,Y,Z}$ = the x, y, and z missile velocity components.

The decoy to target relative velocity components are:

$$V_{DTX} = V_{DX} - V_{TX} \qquad [2.8\text{-}53]$$

$$V_{DTX} = V_{DX} - V_{TX} \qquad [2.8\text{-}54]$$

$$V_{DTX} = V_{DX} - V_{TX} \qquad [2.8\text{-}55]$$

where:

$V_{DX,Y,Z}$ = the x, y, and z decoy velocity components
$V_{TX,Y,Z}$ = the x, y, and z target velocity components
$V_{DTX,Y,Z}$ = the x, y, and z decoy to target relative velocity components

The closing velocities from the decoy to the missile and the target to the missile can be written:

$$V_{MD} = \frac{V_{DMX}R_{DMX} + V_{DMY}R_{DMY} + V_{DMZ}R_{DMZ}}{R_{DM}} \qquad [2.8\text{-}56]$$

$$V_{TD} = \frac{V_{DTX}R_{DTX} + V_{DTY}R_{DTY} + V_{DTZ}R_{DTZ}}{R_{TM}} \qquad [2.8\text{-}57]$$

where:

$R_{DMX,Y,Z}$	=	Range from decoy to missile in x, y, and z components
$R_{DTX,Y,Z}$	=	Range from decoy to target in x, y, and z components
V_{MD}	=	Closing velocity between the missile and decoy
V_{TD}	=	Closing velocity between the target and decoy.

The missile decoy Doppler relative to the illuminator is then calculated:

$$\omega_{dMD} = \omega_d - \frac{(V_{MD} + V_{TD})}{\lambda} \qquad [2.8\text{-}58]$$

The radar's perceived range from the missile to the decoy is:

$$R_{PERC} = R_{TD} + R_{DM} + R_{JTDEL} \qquad [2.8\text{-}59]$$

where:

R_{PERC}	=	perceived range of the missile to the decoy
R_{JTDEL}	=	Range equivalent for jammer time delay.

Design Element 8-8: Complex Voltage from Terrain Bounce Jamming

The complex terrain bounce jamming voltage for the sum, azimuth difference and elevation difference channels is then calculated as described in Section 2.5. The complex voltages are put on the bus and passed to the signal processing FE.

Design Element 8-9: Complex Voltage from Cross-eye Jamming

The ESAMS waveform generator for cross-eye is used to develop the radiation patterns for two antennas mounted on the target aircraft. Time stepped tables for two radiating antennas generate waveforms 180° out of phase as specified in input tables. In the simulation, the jammer receiver detects the aircraft signal, looks up the phase shift in the table for the current time, boosts the signal as specified in the table, and calculates the waveform from the jammer's two antennas. The equations used to calculate the complex voltages introduced into the radar receiver are the standard sum, azimuth difference and elevation difference equations described in other FE's and are not repeated here. The complex voltages are put on the bus and passed to the signal processing FE.

Design Element 8-10: Complex Voltage from VGPO, RGPO, and RVGPO Jamming

As with cross-eye there is no special code to implement VGPO, RGPO, and RVGPO. Gate stealing is implemented through its waveform defined in tables. The time stepped tables define Doppler shifts, relative power, relative phase shifts, relative polarization, relative pulse widths, and time signal time delays. At each time step through the ECM routine, the needed values are read from the table and complex voltages into the receiver are calculated. The equations used to calculate the complex voltages introduced into the radar receiver are the standard sum, azimuth difference and elevation difference equations described in other FE's and are not repeated here. The complex voltages are put on the bus and passed to the signal processing FE.

2.8.3 Functional Element Software Design

This section describes the software design necessary to implement the functional element requirements for deceptive on-board ECM, as outlined in section 2.8.1 and the design approach as outlined in section 2.8.2. Section 2.8.3 is organized as follows. This first section has four subparts: The first subpart describes the overall subroutine hierarchy and gives capsule descriptions of the relevant subroutines; the second subpart contains functional flow charts for the functional element as a whole, and describes the major operations represented by each block in the charts; the third subpart presents detailed logical flow charts for the subroutines; and the last subpart contains a description of all input and output for the functional element as a whole and for each subroutine that implements the functional element.

ECM Deceptive On-Board Subroutine Hierarchy

The Fortran call tree that will be implemented for the ECM Deceptive On-Board Functional Element in the ESAMS 2.7 computer code is shown in Figure 2.8-6. The diagram depicts the entire model structure from the top level ZINGER (the Main subprogram) through al the routines allocated to the functional element. Subroutines allocated directly to the implementation of the functional element are shaded. Subroutines which use functional element results are shown with a heavy-line box. The subroutines allocated to the functional element are listed in Table 2.8-1, together with brief descriptions of them.

The call tree for the on-board deceptive ECM structure shows that there are three different paths to reach the top level routine for the deceptive ECM calculations in ESAMS. This routine is BEMGRM, and it may be reached through the following: SKRCPI, WFTCPI, and TWSYNC. SKRCPI provides access to missile seeker code, WFTCPI is the entree to the ground radar tracking calculations for the waveform driven systems (2 and 3 channel monopulse), and TWSYNC handles the time stepped systems (track-while-scan).

For the tracking modes of the fire control radars and the missile seekers, deceptive jamming (either continuous or SSW) is injected through the GENEXC subroutine. GENEXC calls the individual signal generators which develop the following individual signals: target return, multipath and clutter, thermal noise, and ECM. As shown in Figure 2.8-6, GENEXC activates jamming through a call to BEMGRM.

Under BEMGRM is the key subroutine BEMSEN. This subroutine accesses crucial code that mates the victim sensor with the ECM. BEMSVL and BEMTVL mate the seeker and the fire control radar respectively. The third pertinent subroutine under BEMSEN is BEMANT, and this subroutine has the function of defining the sensor antenna position.

TABLE 2.8-1. On-Board Deceptive ECM Subroutine Description.

Module Name	Description
ECMINI	Initializes ECM inputs, arrays, pointers, and flags.
BEMGRM	Checks each technique in the ECMD file to see if it is active at the current time against the current radar. Serves as top level routine for ECM calculations
BEMSEN	Sets up engagement features between the jamming aircraft and the ground radar, missile seeker, or missile fuze.
BEMTVL	Calculates relative geometries and orientations between the ground radar and jamming aircraft.
BEMSET	Event message output
BEMSVL	Calculates relative geometries and orientations between the missile seeker and jamming aircraft.
BEMANT	Provides jamming antenna position, velocity, and orientation.
BEMEXC	Loads the current ECM characteristics. These include Doppler, power, phase, polarization, pulse width, and time delay
BEMOUT	Develops the ECM induced voltage in the victim radar receiver.
GETWOB	Determines if a wobbulation sweep pulse is on or off at current time.
ATJREF	Calculates geometric relationships.
ATJBOR	Get decoy angles off boresight.
ATJMPI	Calculates decoy power at missile without terrain effects.
ATJFRC	Calculates Fresnel reflection coefficient.
ATJRSC	Calculates Rayleigh scattering coefficient.
ATJSDC	Calculates spacial distribution coefficient.
ATJSIG	Calculates decoy sum and difference voltages.
ATJDGP	Computes decoy Doppler frequency.
ATJI	Initializes angel tracking jammer.
ATJCON	Passes terrain bounce data to BEMGRM

Figure 2.8-6 includes the subroutines which have a major interaction with the on-board deceptive ECM functional element. The lowest level subroutines interface with utilities which are not shown. Also, some of the subroutines shown in Figure 2.8-6 are thoroughly discussed as part of other functional elements. For example, references [28] and [33] on Threshold and Waveform Generator respectively contain an in-depth discussion of a number of subroutines shown in Figure 2.8-6. However, enough detail on these F.E.'s will be contained here to allow the reader to understand the interactions with the on-board deceptive ECM.

ECM Deceptive On-Board Functional Flow

Figure 2.8-7 shows the top-level functional flow of the on-board deceptive ECM implementation. Subroutine names appear in the parentheses at the bottom of each process block. The numbered blocks are described below.

Block 1. The radar mode to jam is extracted from the ECMD file. It can be any (TECMOD=0), the acquisition mode (TECMOD=1), the track mode (TECMOD=2), or jamming to commence after the missile is fired (TECMOD=3).

Block 2. Relative or absolute is set for the various jamming characteristics based on the setting of the “ROA” parameter in the ECMD file. Relative is with respect to the victim radar waveform, while absolute means it is independent of the victim waveform. If the “ROA” parameter is set to one, the value of the characteristic is absolute. If it is zero, the values are relative. For example, DLYROA equal one means that the time delay of the jam signal is absolute. The jamming characteristics set to absolute or relative are frequency, amplitude, phase, polarization, pulse width, and time delay.

Block 3. Environmental values are obtained for the ground radar or missile seeker by calling BEMTVL or BEMSVL respectively.

Blocks 4 and 5. Relative geometry and orientation between the victim sensor and the jamming aircraft are obtained. This data sets the stage for calculations in blocks 6 and 7.

Blocks 6 and 7. The elements of the RADVLU array that are filled are: Doppler due to radar transmitter (TX) and jammer aircraft velocity; power returned to the jamming aircraft; phase at the jamming aircraft due to TX and aircraft separation; received power from the victim radar at the aircraft (includes victim sensor and jammer antenna attenuations); pulse width of victim radar TX; relative closing velocity between the victim sensor and the jamming aircraft; victim receiver voltage gains in the direction of the jamming aircraft for the sum, azimuth difference, and elevation difference channels respectively; and target RCS in the direction of the victim sensor.

Blocks 8, 9, and 10. The end result of these blocks is to provide the ECM waveform. Block 12 is necessary in the alternate route flow to set the jam on-time to zero if it is not specified base on the threat mode. The ECM waveform parameters—either relative or absolute depending on the “ROA” parameters—are Doppler, power, phase, polarization, pulse width, and time delay.

Block 11. When a wobbulation technique is in use, the jam signal will be either on or off, depending on whether the current simulation time is within a scheduled wobbulation pulse or between pulses, respectively. This block provides a flag value of one if the current time is within a pulse, or a value of zero if it is in the dead time between pulses.

Block 12. The number of techniques is specified in the ECMD file. As illustrated earlier, the cross-eye jamming treated each of the jamming antennas—which radiated 180° out of phase with each other as a technique. Thus, there were twelve jamming techniques specified, and the jamming power for each of the techniques must be added to the sum of the power of the previous techniques.

Blocks 13, 14, 15, and 16. The parameter ANTSEL in the ECMD file selects either an omni-directional antenna (ANTSEL.GT.0) or a specific antenna with a specific pattern (ANTSEL.LE.0). If the antenna is omni-directional, the orientation of the jamming aircraft and victim sensor is not important. For the latter case, the jamming antenna which is pointed most directly at the victim sensor is determined. The antenna’s location in inertial coordinates is obtained and, at a later time, its gain in the direction of the victim sensor is established.

Block 17. The jammer antenna inertial coordinates with respect to the victim sensor are obtained.

Block 18. Special signals are transferred to the ESAMS bus. These include victim sensor wavelength, loss factors, and antenna error slopes.

Block 19. The call to BEMOUT generates the sum and difference channel complex voltages, apparent range, and Doppler shift of the jamming signal at the victim sensor. The signal has been attenuated appropriately for the transmitter and receiver antenna gains.

Block 20. Geometric calculations are made so that the position of the TB decoy point with respect to the target aircraft and missile seeker is known. Relevant angles are also computed.

Block 21. The decoy angles off of the jammer antenna boresight are obtained. This information is used to determine jammer antenna gain magnitude in the direction of the decoy.

Block 22. Radar Range equation methodology is used to determine the decoy jam magnitude at the missile seeker. Terrain effects—due to surface reflexivity and scattering—are not yet included.

Block 23. Fresnel reflection coefficient is computed to determine jammer loss due to imperfect reflecting surfaces. ECMD file contains terrain with different dielectric properties. Computed for vertical polarization.

Block 24. Rayleigh scattering coefficient is calculated to determine amount of decoy energy due to specular reflection. This component dies out quickly with terrain roughness.

Block 25. The spatial distribution coefficient is calculated to determine the decoy energy due to diffuse reflection. The methodology used is based on test data compiled by Hughes and Raytheon.

Block 26. The decoy sum and difference voltages at the missile seeker are determined. These include terrain effects and represent the actual impact on the missile seeker due to TB.

Block 27. Decoy Doppler frequency is computed. This information is used to determine bounce signal impact on seeker Doppler tracking.

Block 28. TB executive routine (ATJCON), which calls the other ATJ routines, passes the key data to BEMGRM for insertion on the ESAMS bus.

Block 29. Since the jamming is developed for the different techniques, a check is made and power reduced if necessary, to insure that the power available is not exceeded.

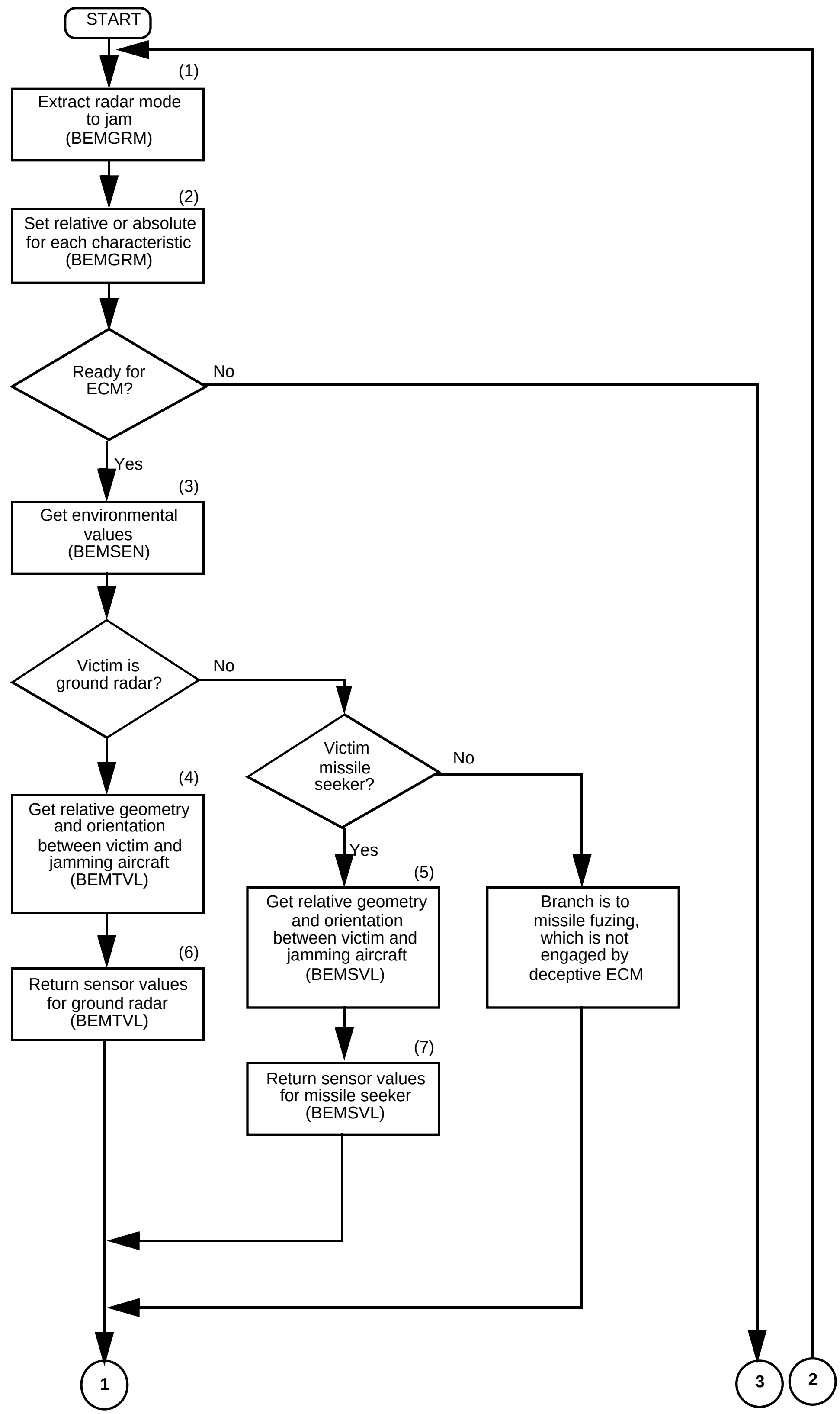


FIGURE 2.8-6. On-Board Deceptive ECM Functional Flow Diagram.

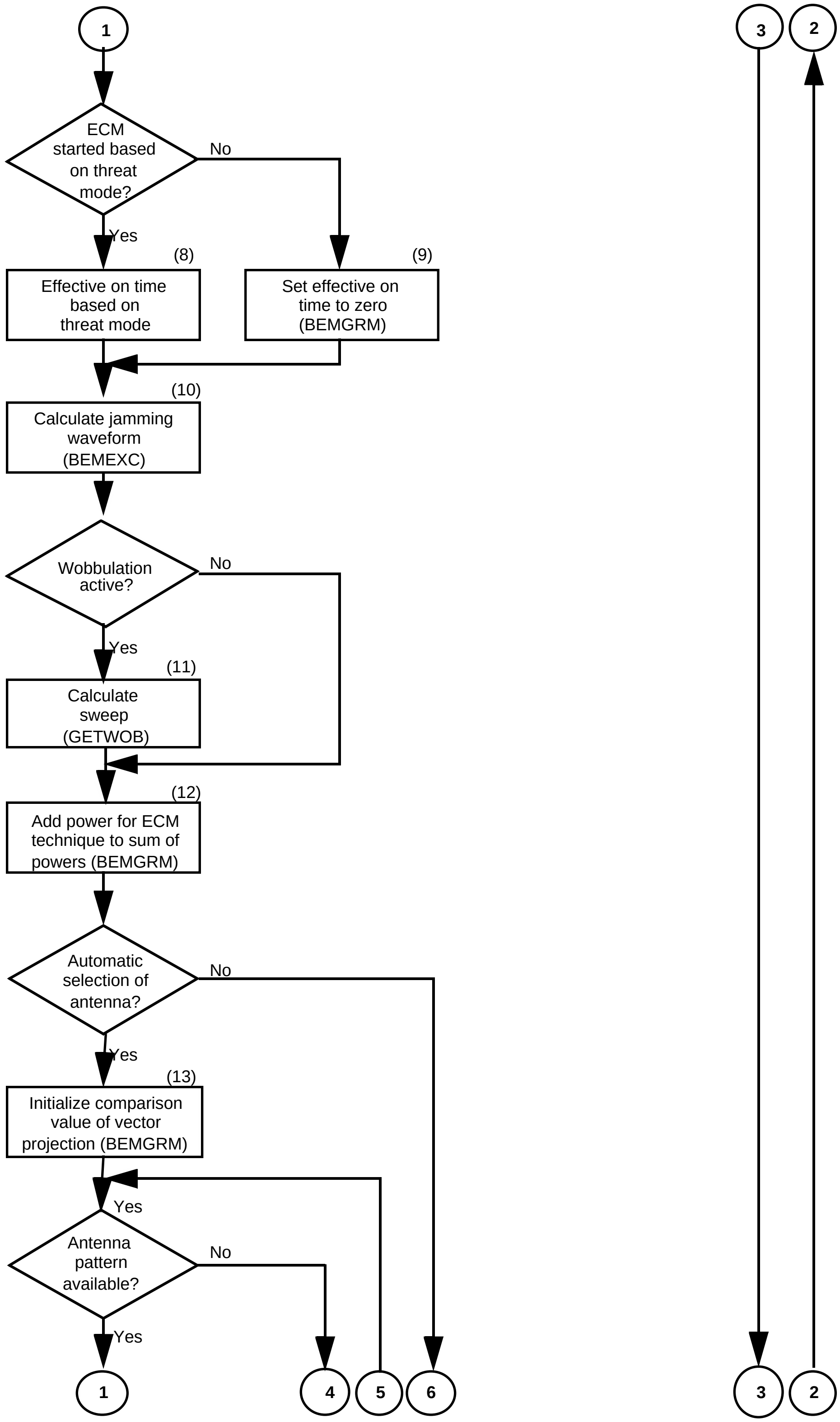


FIGURE 2.8-6. On-Board Deceptive ECM Functional Flow Diagram. (Contd.)

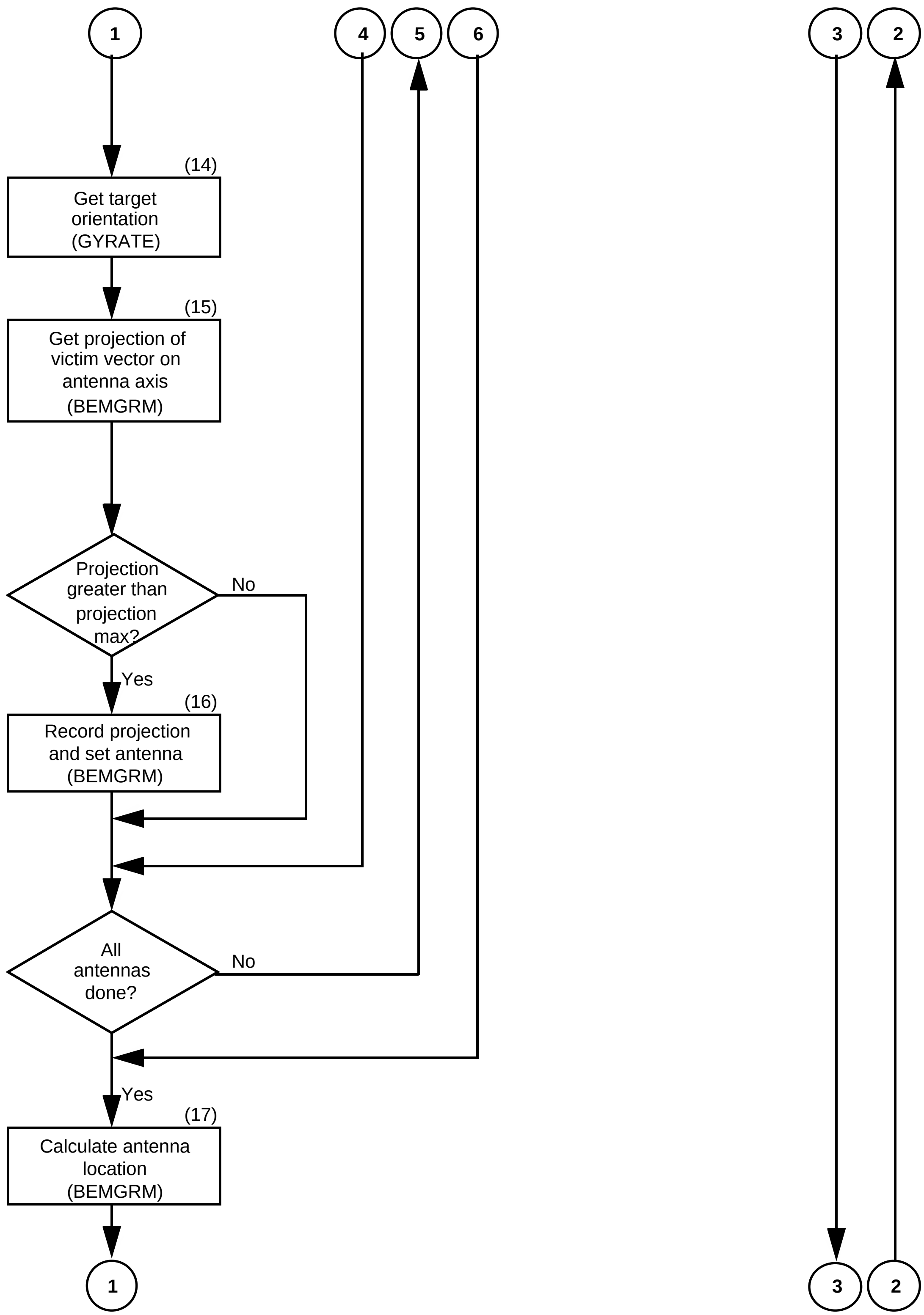


FIGURE 2.8-6. On-Board Deceptive ECM Functional Flow Diagram. (Contd.)

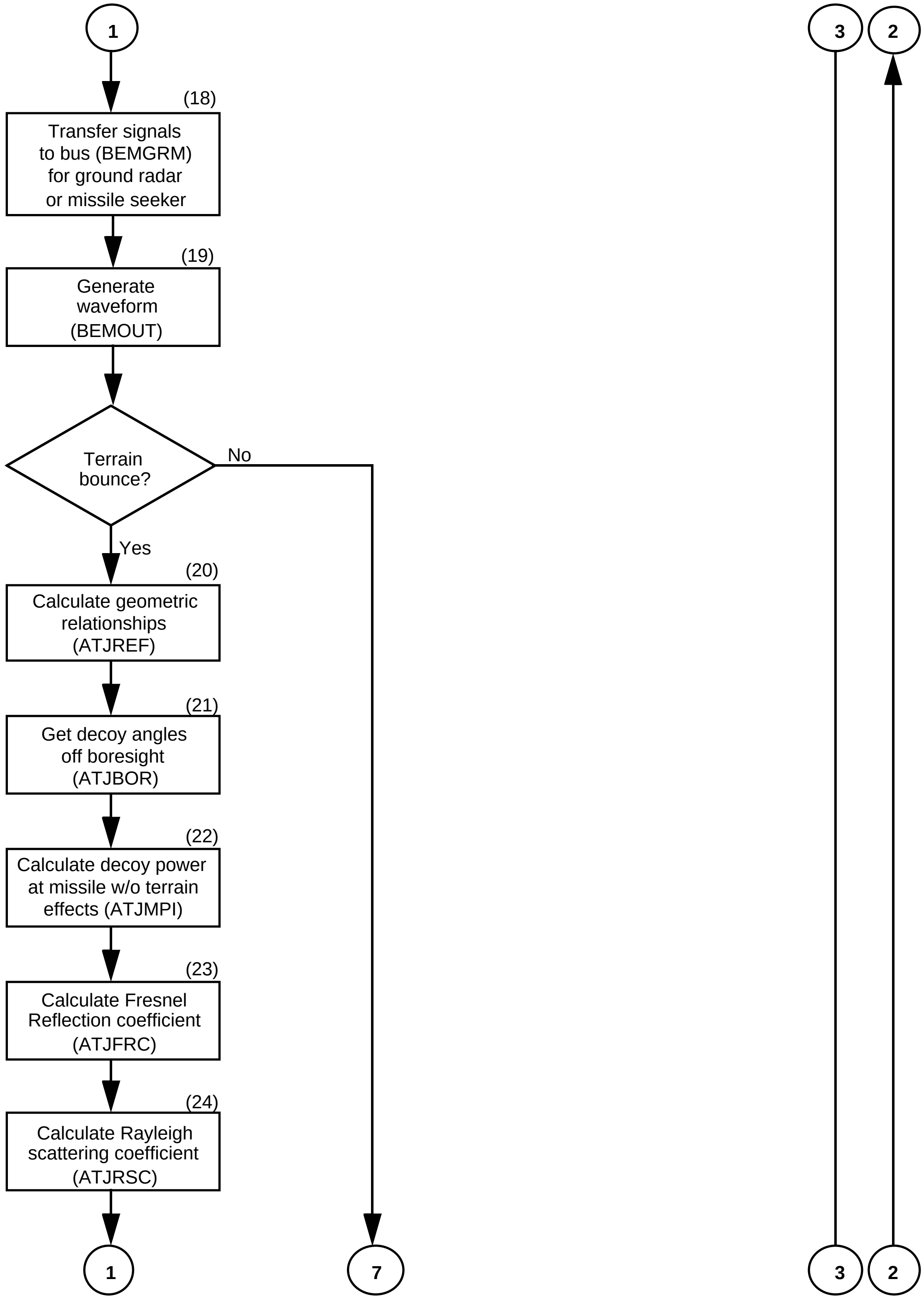


FIGURE 2.8-6. On-Board Deceptive ECM Functional Flow Diagram. (Contd.)

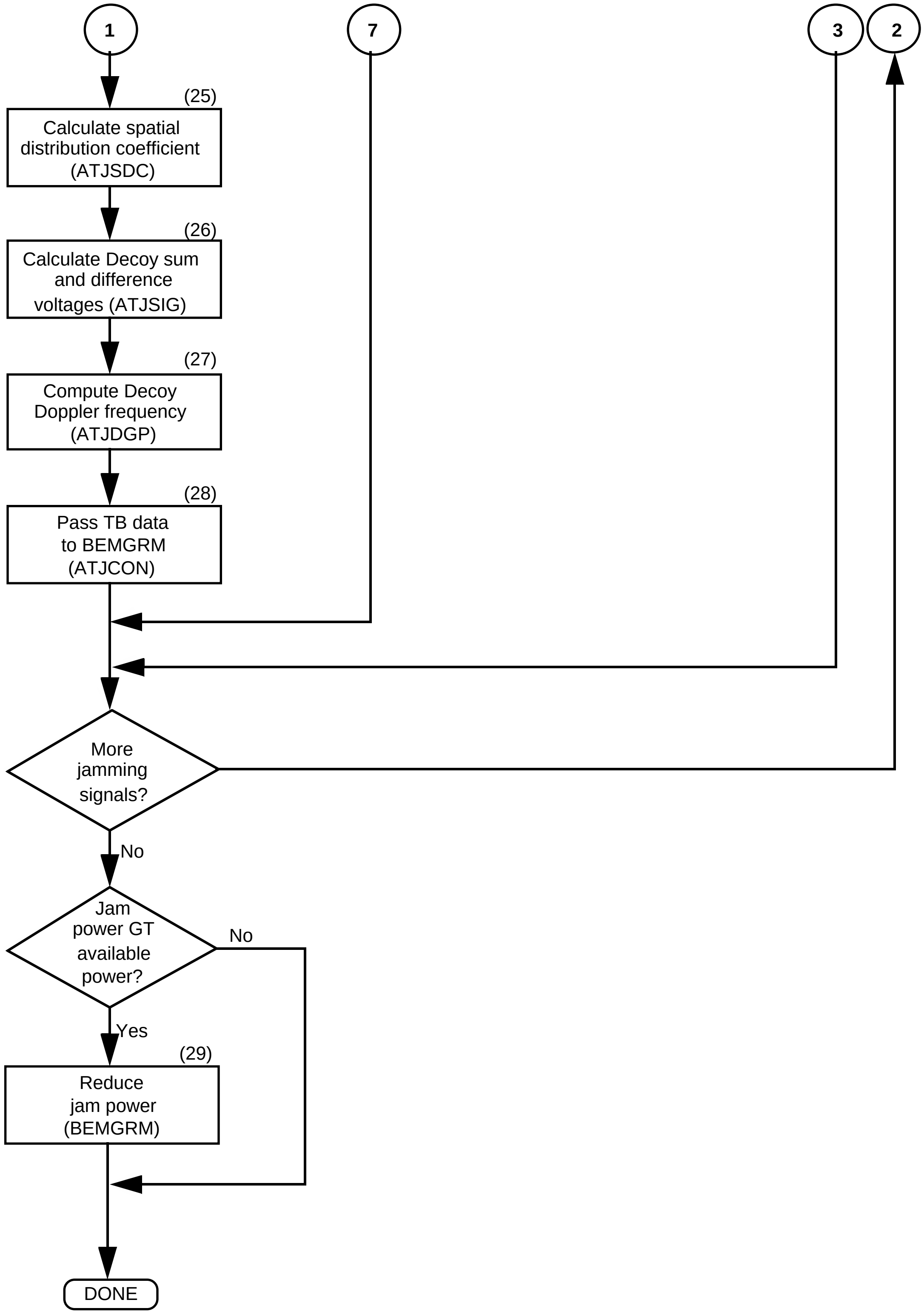


FIGURE 2.8-6. On-Board Deceptive ECM Functional Flow Diagram. (Contd.)

Subroutine Flow Charts

The functional flow diagrams of the ECM subroutines which support on-board deceptive ECM are presented below, in Figures 2.8-8 through 2.8-18. The higher level routines which call the ECM algorithms and interface their functioning with routines that determine impact on tracking are not diagrammed here. This is due to the fact that they are diagrammed in the other VSDR documents which deal with their specific functional performance such as Threshold [28] and Waveform Generator [33]. However, some appropriate comments are made here to reinforce how the jamming is introduced into acquisition and tracking determination.

Many of the other ECM subroutines have already been documented in FE 2.5. The functional flow diagrams and I/O tables for those subroutines are not repeated in this FE. Table 2.8-2 shows those lower level ECM subroutines which are not included here and the FE in which they are included.

There are three different areas in ESAMS which can be impacted by on-board deceptive ECM: (1) waveform driven ground radars during tracking; (2) time stepped TWS radars during track; and (3) missile seeker operation.

Subroutines SKRCPI and WFTCPI interface with jamming code through the subroutine GENEXC. SKRCPI and WFTCPI are the Coherent Processing Interval (CPI) code for the seeker and ground radar tracking mode respectively. The CPI code is the lowest level of processing, followed by sequence and group processing. Sequence processing, for example, keeps a running total of angle, range, and Doppler errors plus the number of errors accumulated. The Group level then averages the data and furnishes this information to the appropriate subroutines so that angle, range, and Doppler “gates” are repositioned.

Subroutine SKRCPI also has some ECCM that would be appropriate to deceptive jamming. Some of the seeker systems have a surge detector. The presence of this detector is identified by the following parameters in the RDRD file:

SRGWIN—Surge detector filter time constant

THRSHS—Surge detection threshold

SRGFCT—Minimum time after track for surge declaration

If a surge detector is specified, then SKRCPI calls HOJCHK to determine if home-on-jam should be implemented. The HOJCHK subroutine checks voltage level signals in the Doppler guard gates to see if the HOJ threshold has been exceeded. If so, the Doppler gate can be frozen, and HOJ tracking implemented. This ECCM will be thoroughly discussed in the Doppler tracking VSDR for ESAMS 2.7. As mentioned previously, WFTCPI provides interface to the ECM techniques for the waveform driven ground radar tracking. ECCM techniques employed by the ground radar are the following:

1. Range Blanking Pulse. The logic for this technique is contained at the CPI level.
2. Range Gate Repositioning. If selected, this option will reposition the range gate to the position of the guard gate alarm. This logic is contained in subroutine ARGPOA.

3. Range Rate/Doppler Comparisons. This technique is available to any system that tracks Doppler and range gate rate. A check is made of the difference between the range gate rate and the closing rate given by (wavelength*Doppler/2.0). If the difference between these values exceeds the threshold given by RDOTVT, then the comparison alarm is set. Note that the alarm threshold is input in meters per second. This check is disabled if the alarm threshold is zero.

4. Doppler Gate Repositioning. If selected, this option will reposition the Doppler gate as determined by the logic in subroutine AVGPOA.

These techniques are interfaced through a call to subroutine WFTCCM from WFTCPI. As mentioned earlier, the ECCM code is part of the tracking VSDRs.

For the time-stepped TWS systems, TWSEC calls GENEXC which in turn calls BEMGRM when ECM is to be employed. Presently, there is no explicit ECCM code for the TWS systems as there is for other ground trackers and the seekers.

Terrain bounce is the one deceptive technique that uses essentially unique code. Subroutine ATJCON calls other subroutines—all starting with ATJ—that figure the contribution of specular and diffuse terrain bounce reflections on ECM performance. The functional flow diagrams for the on-board deceptive ECM (not including subroutines delineated in Table 2.8-2) follow.

TABLE 2.8-2. Subroutine Flow Diagram Cross-Reference.

Subroutine	ASP-II Figure inwhich flow diagram is contained
BEMGRM	2.5-3a
BEMEXC	2.5-3b
BEMSEN	2.5-3c
BEMFVL	2.5-3d
BEMSVL	2.5-3e
BEMTVL	2.5-3f
BEMANT	2.5-3g
BEMOUT	2.5-3h
BEMNZ	2.5-3i
BEMSET	2.5-3j

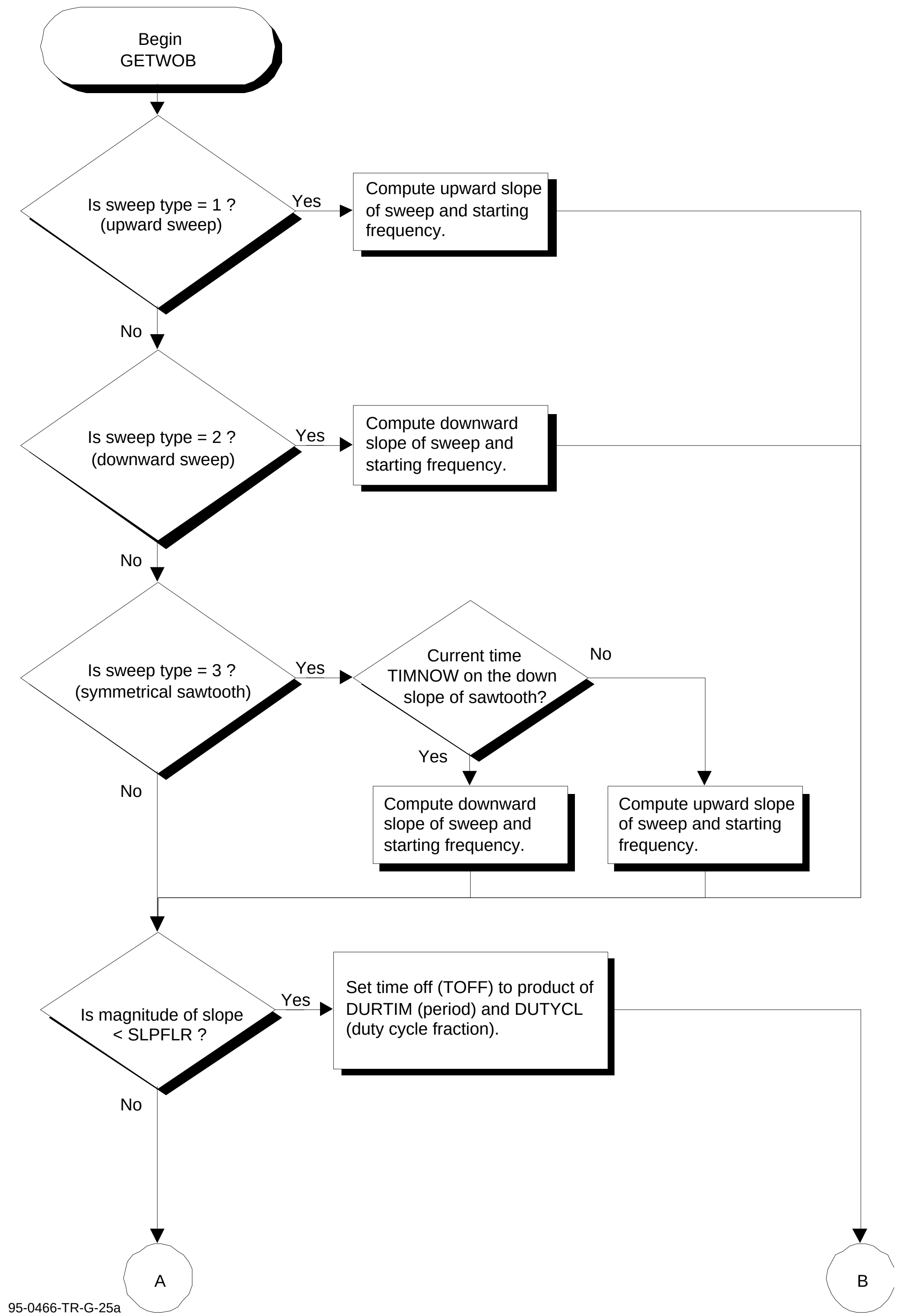


FIGURE 2.8-7. Functional Flow Diagram for Subroutine GETWOB.

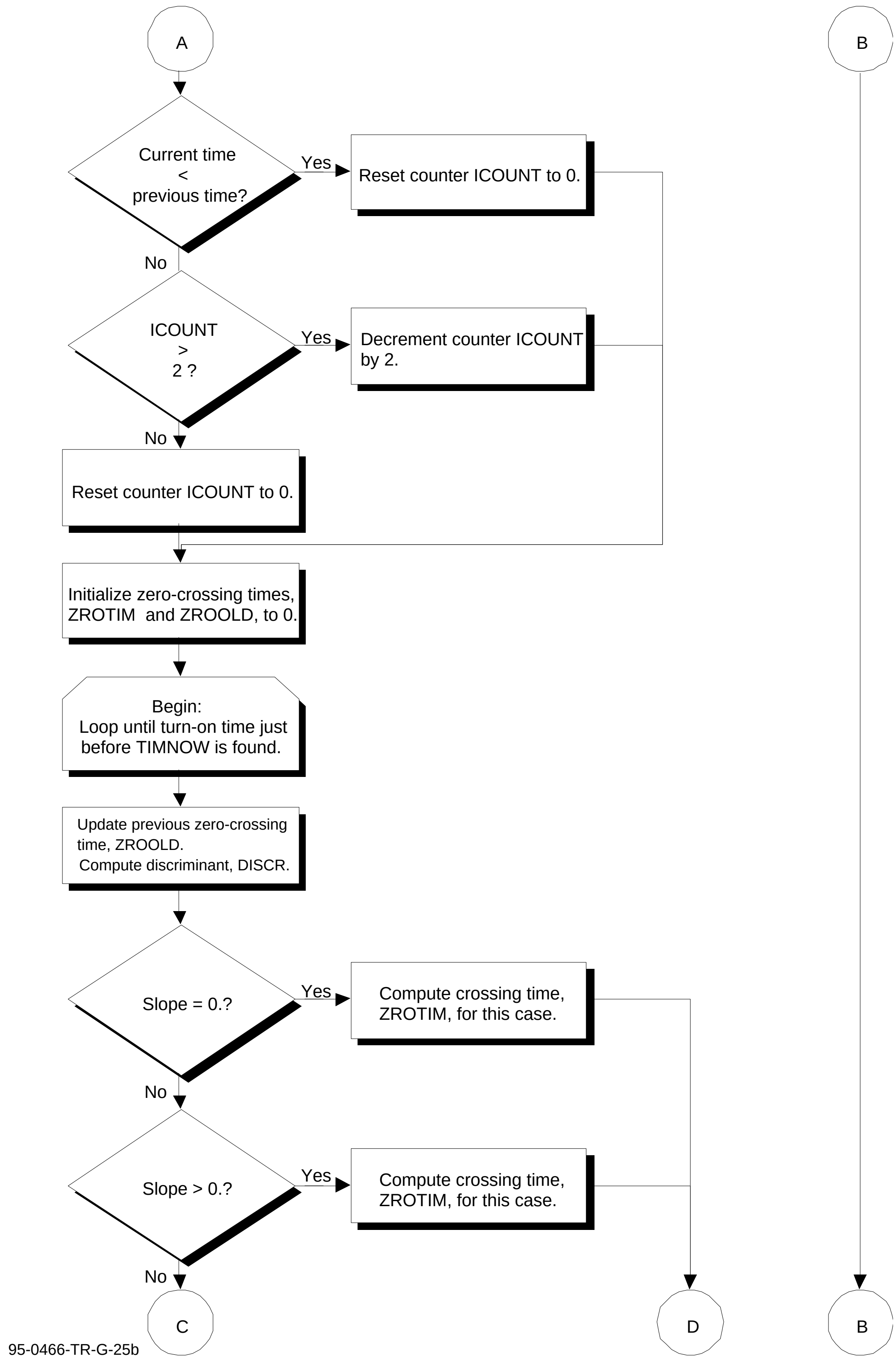


FIGURE 2.8-7. Functional Flow Diagram for Subroutine GETWOB. (Contd.)

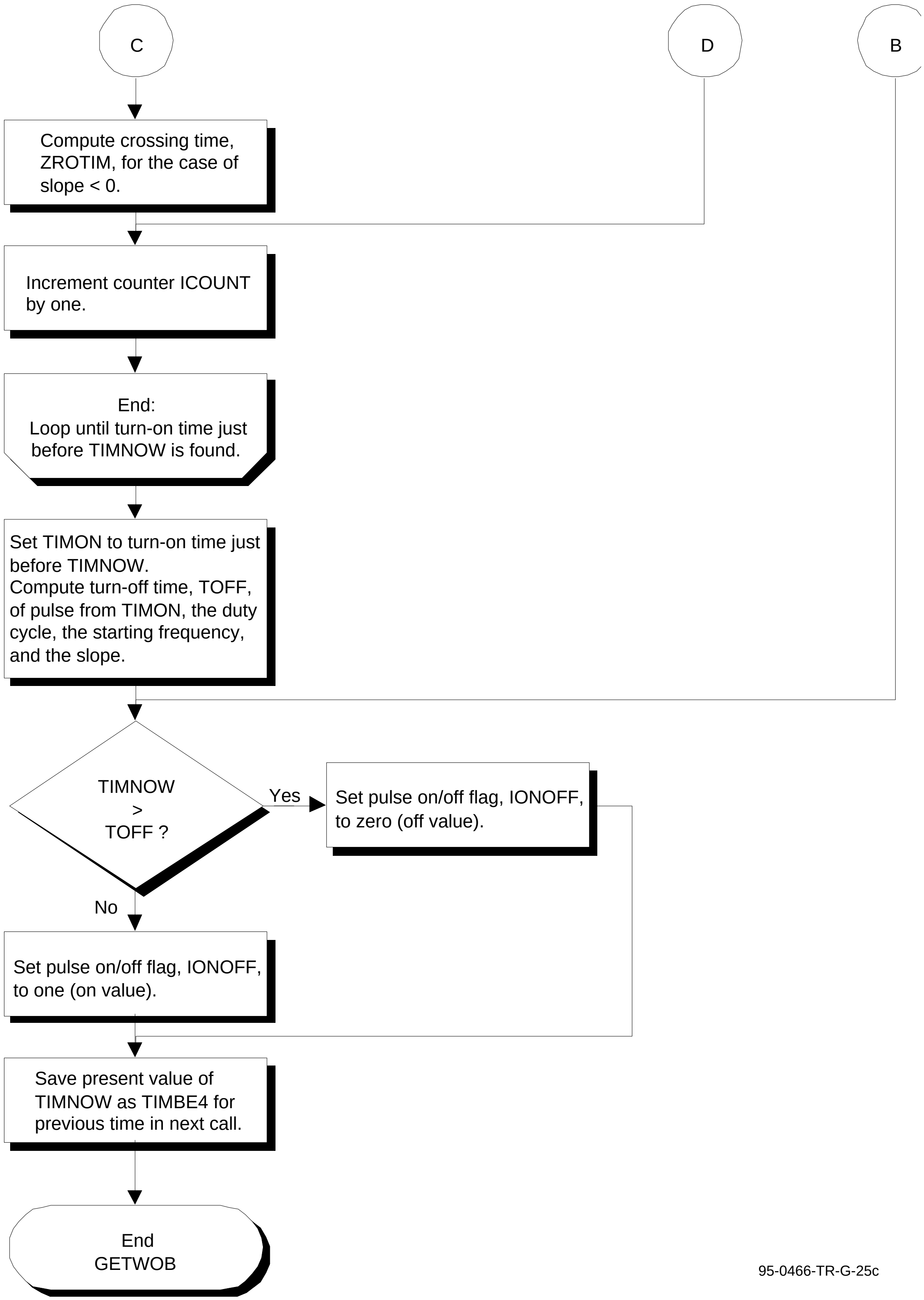


FIGURE 2.8-7. Functional Flow Diagram for Subroutine GETWOB. (Contd.)

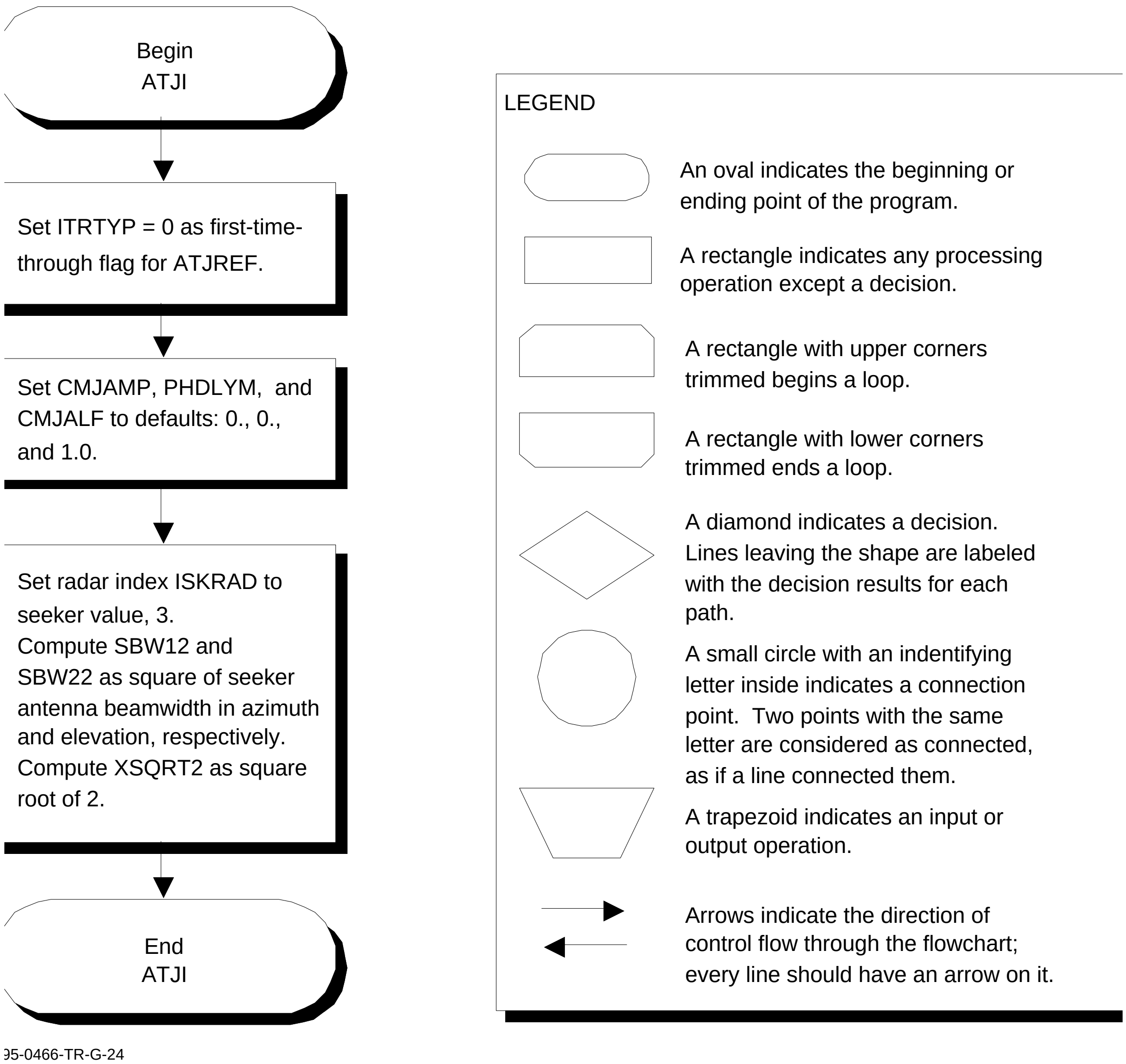


FIGURE 2.8-8. Functional Flow Diagram for Subroutine ATJI.

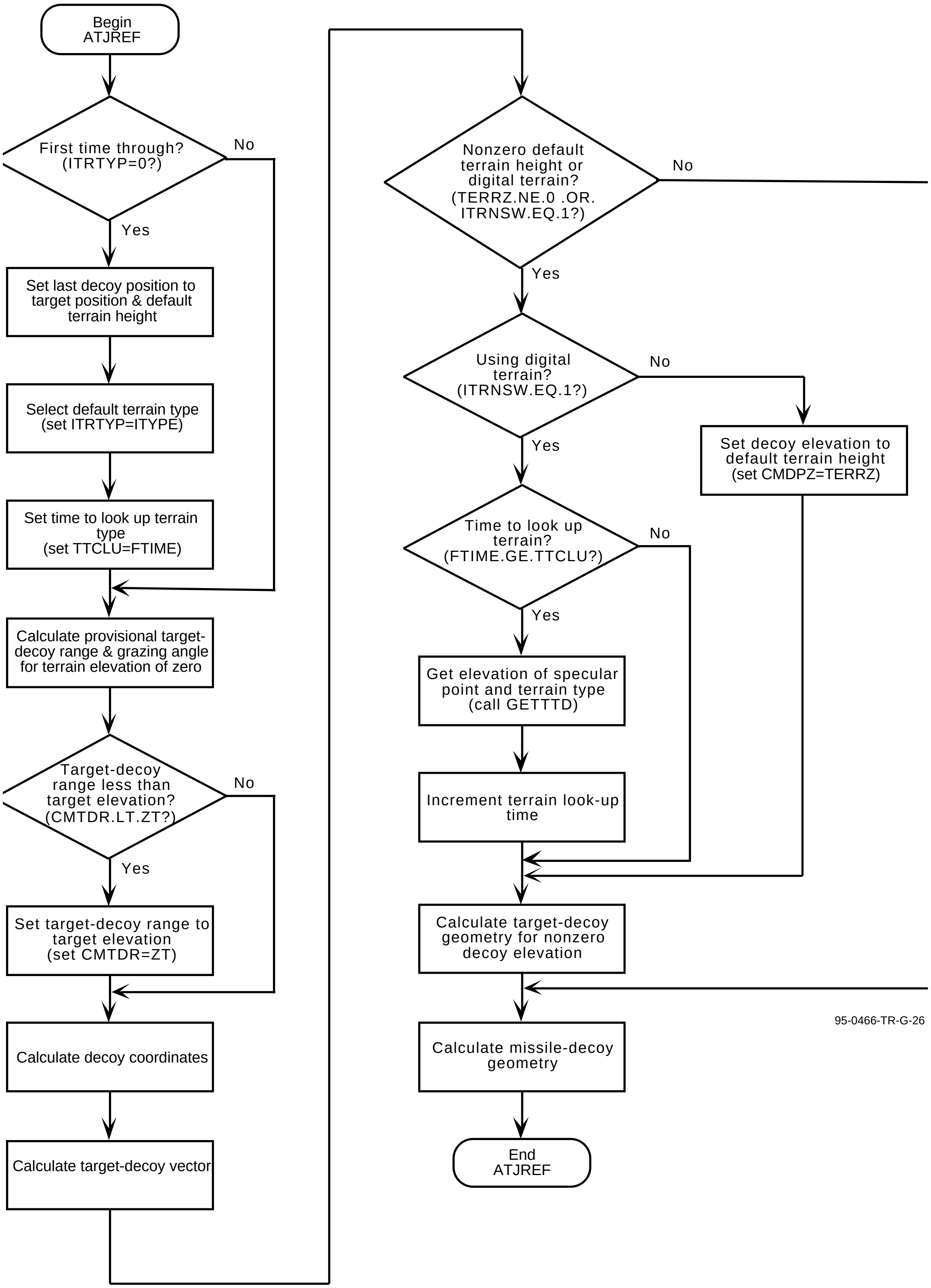


FIGURE 2.8-9. Functional Flow Diagram for Subroutine ATJREF.

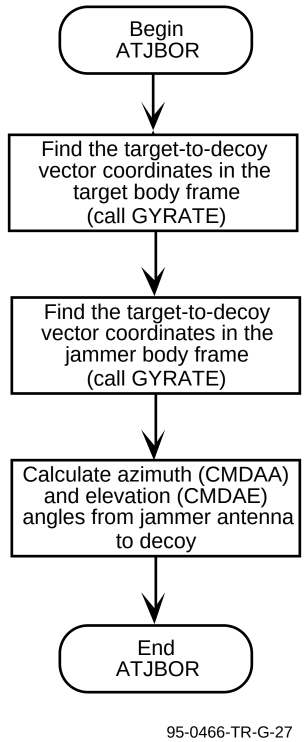


FIGURE 2.8-10. Functional Flow Diagram for Subroutine ATJBOR.

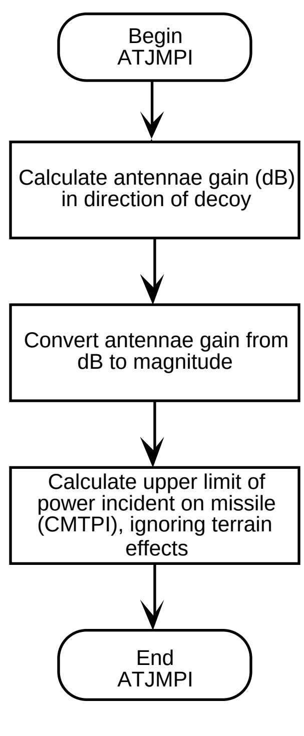


FIGURE 2.8-11. Functional Flow Diagram for Subroutine ATJMPI.

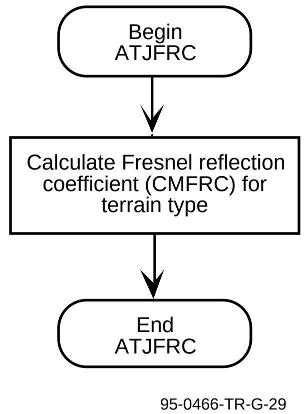


FIGURE 2.8-12. Functional Flow Diagram for Subroutine ATJFRC.

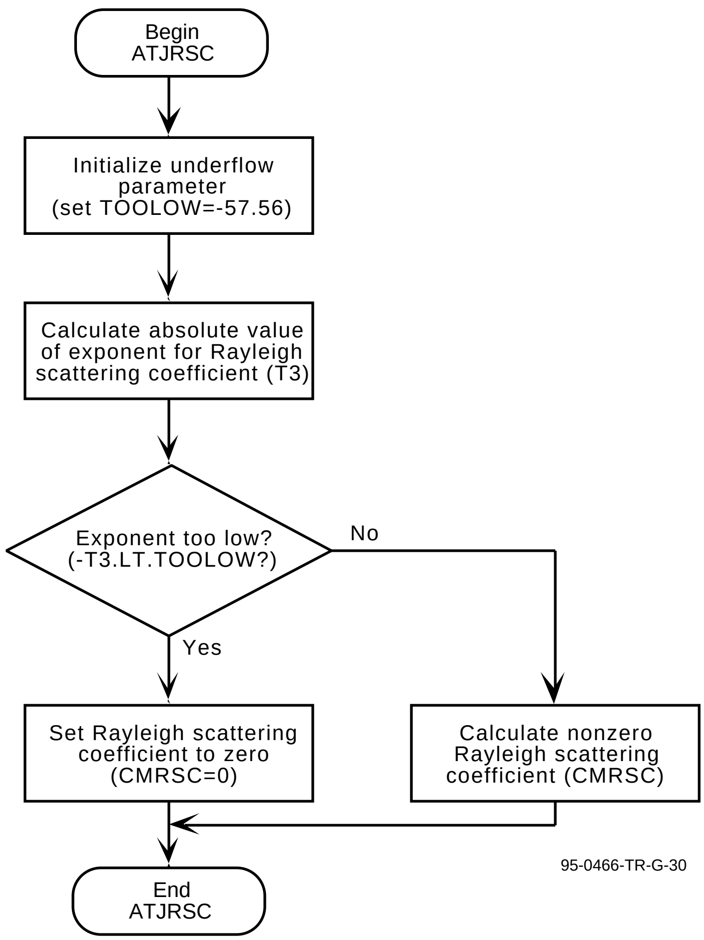


FIGURE 2.8-13. Functional Flow Diagram for Subroutine ATJRSC.

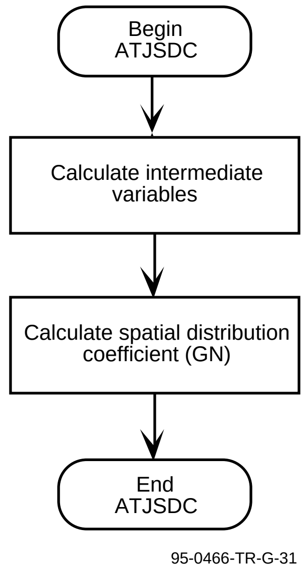


FIGURE 2.8-14. Functional Flow Diagram for Subroutine ATJSDC.

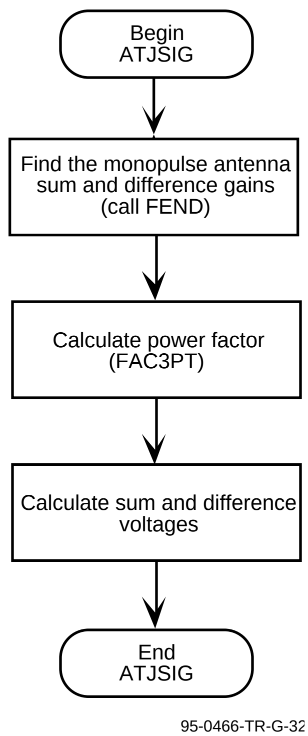


FIGURE 2.8-15. Functional Flow Diagram for Subroutine ATJSIG.

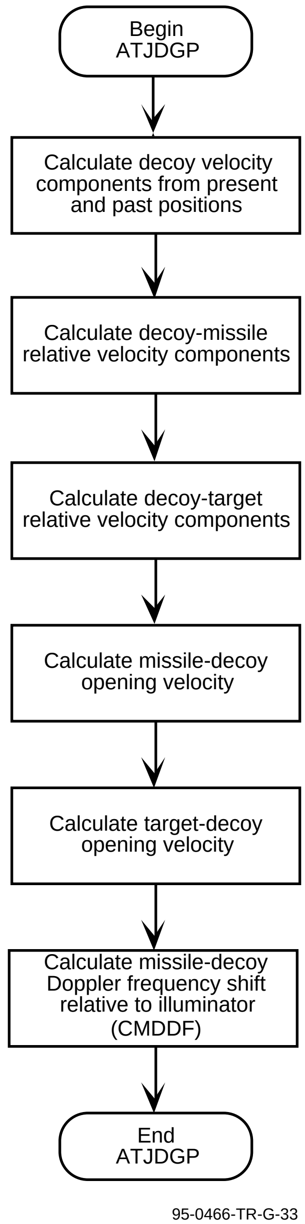


FIGURE 2.8-16. Functional Flow Diagram for Subroutine ATJDGP.

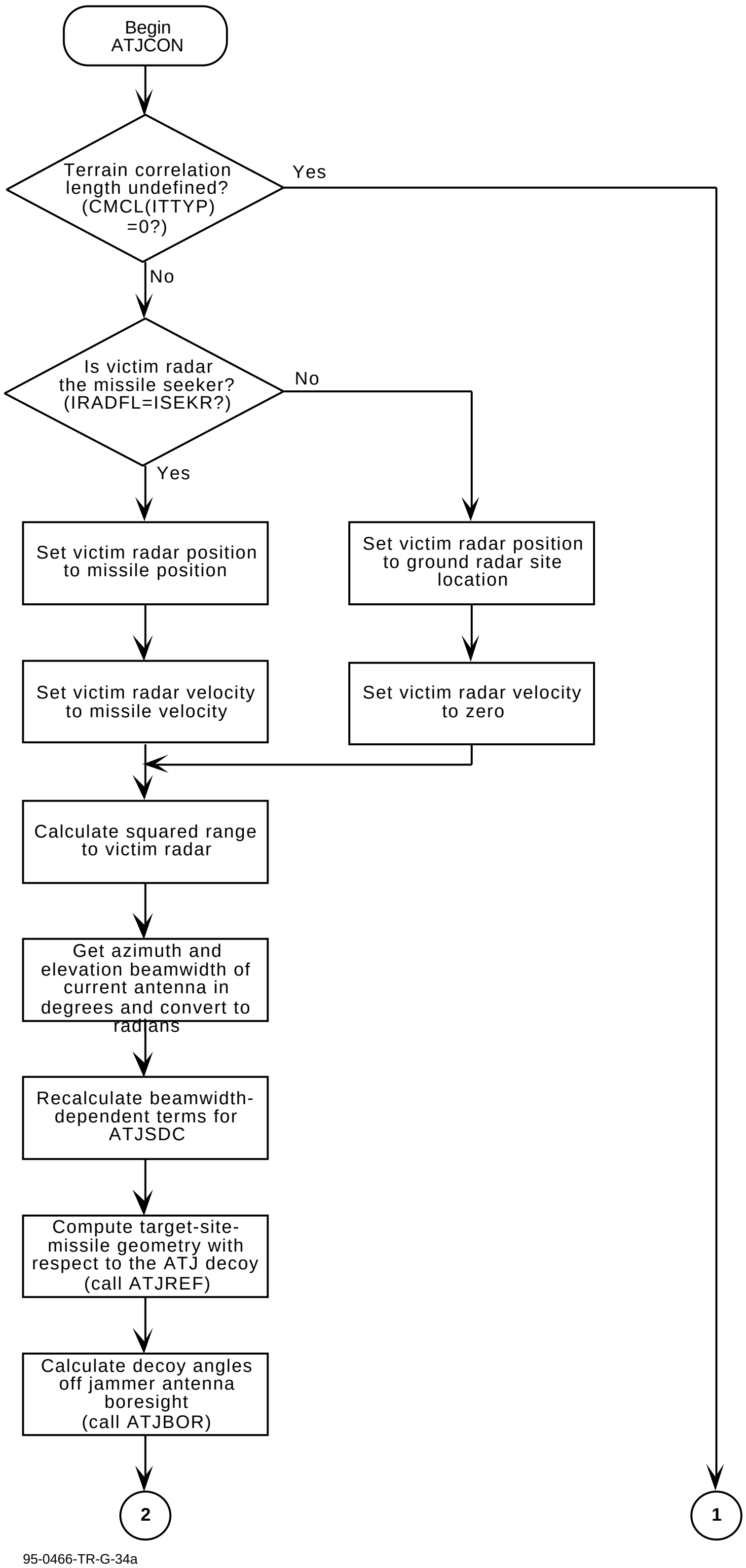


FIGURE 2.8-17. Functional Flow Diagram for Subroutine ATJCON.

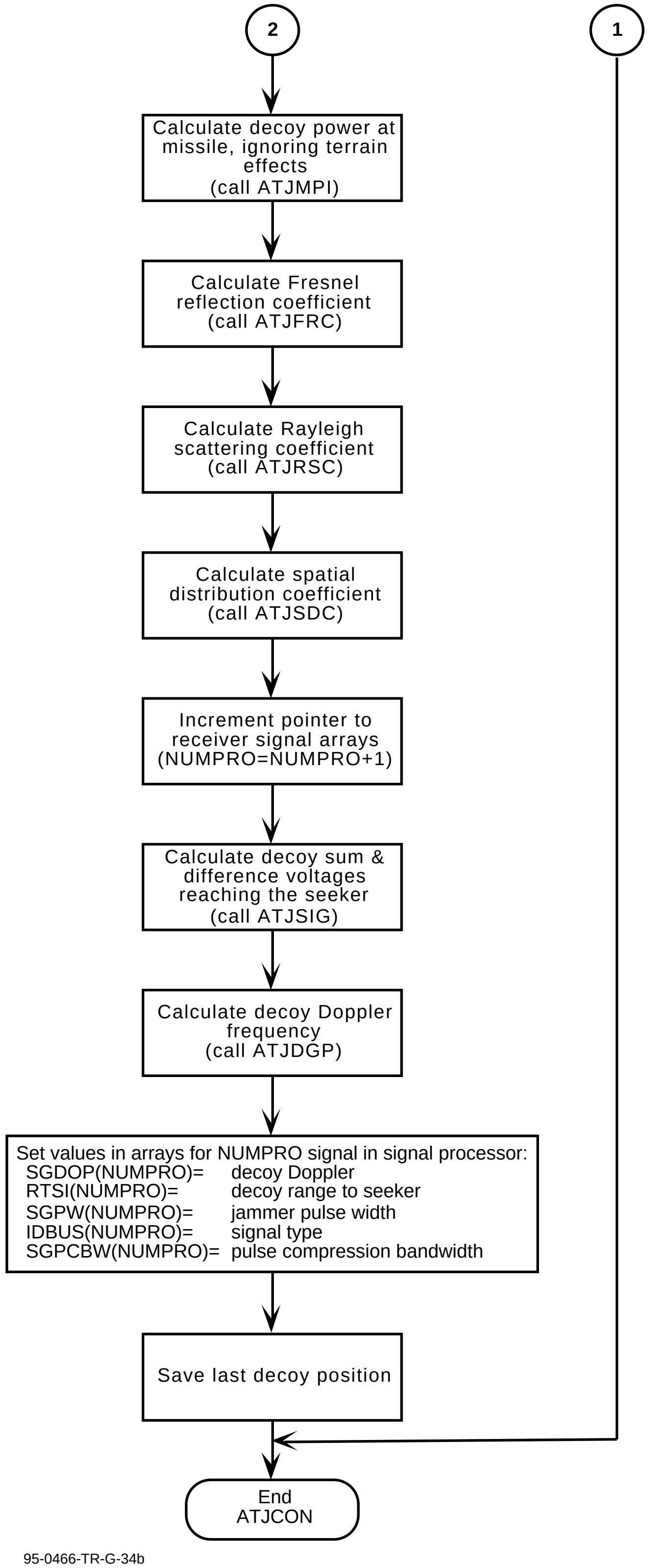


FIGURE 2.8-17. Functional Flow Diagram for Subroutine ATJCON (Contd.)

On-Board Deceptive ECM Inputs and Outputs

The model inputs that effect the on-board deceptive ECM functional element are listed in Table 2.8-3.

TABLE 2.8-3. On-Board Deceptive ECM Model Inputs.

Name	Source	Description
AMPROA(-)	Common ECMD	Array of flags indicating whether jammer amplitudes are relative or absolute. (=0, relative; otherwise, absolute; =2, case of repeater gain on power) Dimensioned NUMTEC (= 50).
ANSLW(-)	Common ECMD	Flag for whether the antenna is slewable. (=0, fixed; =1, slewable). (Real form) Dimensioned NUMANT (=10).
ANTPAZ(-)	Common ECMD	Array of jammer antenna pointing angles in azimuth. Dimensioned NUMANT (=10).
ANTPEL(-)	Common ECMD	Array of jammer antenna pointing angles in elevation. Dimensioned NUMANT (=10).
ANTSEN(-)	Common ECMD	Pointer to the antenna being used for environment sensing. Dimensioned NUMTEC (=50).
ANTXLO(-)	Common ECMD	X-component of jammer antenna location on platform. Dimensioned NUMANT (=10).
ANTYLO(-)	Common ECMD	Y-component of jammer antenna location on platform. Dimensioned NUMANT (=10).
ANTZLO(-)	Common ECMD	Z-component of jammer antenna location on platform. Dimensioned NUMANT (=10).
CHRPT(-,-)	Common ECMD	Pointers to jammer characteristics tables in the ECMT work space array. (Real form) Dimensioned NJCHAR (=6) by NUMTEC (=50).
CNTFRQ(-)	Common ECMD	Center frequency for wobbulation generation. Dimensioned NUMTEC (=50).
DLYROA(-)	Common ECMD	Array of flags indicating whether jammer time delays are relative or absolute. (=0, relative; otherwise, absolute) Dimensioned NUMTEC (= 50).
DURTIM(-)	Common ECMD	Duration times for jammer techniques. Dimensioned NUMTEC (=50).
DUTCYL(-)	Common ECMD	Duty cycle for wobbulation generation. Dimensioned NUMTEC (=50).
ECMT(-)	Common ECMD	Workspace array in which jammer tables are kept; pointers locate the tables in ECMT. Dimensioned LECMT (=13757).
FRQROA(-)	Common ECMD	Array of flags indicating whether jammer frequencies are relative or absolute. (=0, relative; otherwise, absolute) Dimensioned NUMTEC (= 50).
OFFFRQ(-)	Common ECMD	Offset frequency for wobbulation generation. Dimensioned NUMTEC (=50).

TABLE 2.8-3. On-Board Deceptive ECM Model Inputs. (Contd.)

Name	Source	Description
PANT(-)	Common ECMD	Pointer to ATJ jammer antenna table. (Real form) Dimensioned NUMANT (=10).
PHSROA(-)	Common ECMD	Array of flags indicating whether jammer phases are relative or absolute. (=0, relative; otherwise, absolute) Dimensioned NUMTEC (= 50).
PLSROA(-)	Common ECMD	Array of flags indicating whether jammer pulse widths are relative or absolute. (=0, relative; otherwise, absolute) Dimensioned NUMTEC (= 50).
POLROA(-)	Common ECMD	Array of flags indicating whether jammer polarizations are relative or absolute. (=0, relative; otherwise, absolute) Dimensioned NUMTEC (= 50).
PWRMAX	Common ECMD	Maximum power for jammer.
RADJAM(-)	Common ECMD	Active list of radars. Dimensioned NUMTEC (=50).
RCVPAT(-)	Common ECMD	Array containing the ECM receiver antenna table. Dimensioned LPATRN (=13757).
RMPTIM(-)	Common ECMD	Ramp time for wobbulation generation (repeat period for wobbulation sweep). Dimensioned NUMTEC (=50).
SWPTYP(-)	Common ECMD	Sweep type index for wobbulation generation. Dimensioned NUMTEC (=50).
TECAZB(-)	Common ECMD	Minimum azimuth of site with respect to target for jammer technique. Dimensioned NUMTEC (=50).
TECAZF(-)	Common ECMD	Maximum azimuth of site with respect to target for jammer technique. Dimensioned NUMTEC (=50).
TECHQN	Common ECMD	Number of jammer techniques to be used.
TECMOD(-)	Common ECMD	Radar mode to apply jammer technique against. Dimensioned NUMTEC (=50).
TECRMB(-)	Common ECMD	Minimum range of site with respect to target for jammer technique. Dimensioned NUMTEC (=50).
TECRMF(-)	Common ECMD	Minimum range of site with respect to target for jammer technique. Dimensioned NUMTEC (=50).
TIMEON(-)	Common ECMD	Beginning of time window for jamming by technique. Dimensioned NUMTEC (=50).
TIMOFF(-)	Common ECMD	Ending of time window for jamming by technique. Dimensioned NUMTEC (=50).
XMTPAT(-)	Common ECMD	Array containing the ECM transmitter antenna table. Dimensioned LPATRN (=13757).
XTDAZ	Common ECMD	Azimuth with respect to target for deployed towed decoy.

The outputs of the on-board deceptive ECM functional element are jam signals on the signal bus, the count of signals on the bus [NUMBRO] incremented for the added jam signals, and times and flags relating to jammer action; these are listed in Table 2.8-4.

TABLE 2.8-4. On-Board Deceptive ECM Model Outputs.

Name	Source	Description
IDBUS(-)	Argument returned from BEMGRM	Array of signal ID values [signal bus].
NUMPRO	Argument returned from BEMGRM	Current number of signals on signal processor bus. Incremented from input value by number of jammer signals placed on signal bus.
RTSI(-)	Argument returned from BEMGRM	Array of ranges for signals [signal bus].
SGDOP(-)	Argument returned from BEMGRM	Array of signal Doppler shifts [signal bus].
SGDVA(-)	Argument returned from BEMGRM	Array of complex azimuth-differential channel signal voltages [signal bus.].
SGDVE(-)	Argument returned from BEMGRM	Array of complex elevation-differential channel signal voltages [signal bus.].
SGPCBW(-)	Argument returned from BEMGRM	Array of signal pulse compression bandwidths [signal bus].
SGPW(-)	Argument returned from BEMGRM	Array of signal pulse widths [signal bus].
SGSV(-)	Argument returned from BEMGRM	Array of complex sum channel signal voltages [signal bus.].
STRTED(-)	Common ECMV	Flags indicating that jammer techniques have started. Dimensioned NUMTEC (=50).
TIMMOD(-)	Common ECMV	Times for which system has been in operating modes. Dimensioned NUMMOD (=6).
TSTECH(-)	Common ECMV	Times at which jamming techniques started. Dimensioned NUMTEC (=50).

Inputs and outputs for the subroutines allocated to the implementation of the on-board deceptive ECM functional element are listed in Tables 2.8-5a through 2.8-15b.

TABLE 2.8-5a. Subroutine GETWOB–Input Data.

Name	Source	Description
SWPTYP(-)	Common ECMD	Array of sweep type indicators (0=none, 1=up, 2=down, 3=sawtooth) for jamming techniques. Dimensioned NUMTEC (=50).
ITCHNQ	Argument	Array index to current jammer channel technique.
OFFFRQ(-)	Common ECMD	Array of offset frequencies for wobbulation for jamming techniques (Hz). Dimensioned NUMTEC (=50).
RMPTIM(-)	Common ECMD	Array of ramp times for wobbulation (time required for a wobbulation sweep) for jamming techniques (sec). Dimensioned NUMTEC (=50).
CNTFRQ(-)	Common ECMD	Array of center frequencies around which wobbulation sweep occurs for jamming techniques (Hz). Dimensioned NUMTEC (=50).

TABLE 2.8-5a. Subroutine GETWOB–Input Data. (Contd.)

Name	Source	Description
TIMNOW	Argument	Time at which it is to be determined whether the wobbulation signal is on or off (sec).
DURTIM(-)	Common ECMD	Array of duration times for jammer techniques (sec). Dimensioned NUMTEC (=50).
DUTCYL(-)	Common ECMD	Array of duty cycles of the wobbulation pulse for jammer techniques. Dimensioned NUMTEC (=50).

TABLE 2.8-5b. Subroutine GETWOB–Output Data.

Name	Source	Description
IONFLG	Argument	Flag indicating state of the wobbulation pulse (0=off, 1=on).

TABLE 2.8-6a. Subroutine ATJI–Input Data.

Name	Source	Description
HPANG	Common FREND	Half-power angle (radians).
HPANGA	Common FREND	Azimuth half-power angle (radians).
HPANGE	Common FREND	Elevation half-power angle (radians).

TABLE 2.8-6b. Subroutine ATJI–Output Data.

Name	Source	Description
CMJALF	Common ECMATJ	Jammer loss factor (magnitude).
CMJAMP	Common ECMATJ	Jammer power (w).
ITRTYP	Common ECMI	Terrain type indicator.
PHDLYM	Common ECMATJ	Jammer phase delay (m).
SBW12	Common ECMATJ	Seeker beamwidth-squared in direction 1 (radians squared).
SBW22	Common ECMATJ	Seeker beamwidth-squared in direction 2 (radians squared).
XSQRT2	Common ECMATJ	Square root of 2.

TABLE 2.8-7a. Subroutine ATJREF–Input Data.

Name	Source	Description
CMDPZ	Common ECMATJ, Return from GETTTD	Decoy position, X coordinate (EFCS) (m).
DTCLUT	Argument	Terrain lookup interval.
FTIME	Argument	Missile flight time (sec).
IRADFL	Argument	Radar type indicator (1=acquisition, 2=tracker, 3=seeker, 4=illuminator).

TABLE 2.8-7a. Subroutine ATJREF–Input Data. (Contd.)

Name	Source	Description
ITRNSW	Argument	Terrain type selection indicator.
ITRTYP	Argument, Return from GETTTD	ATJ terrain type indicator.
ITYPE	Argument	Default terrain type indicator.
RTM2	Argument	RTM squared. (RTM is range from target 1 to victim (missile) radar.)
TERRZ	Argument	Default terrain height (m).
X	Argument	Missile location, X coordinate, inertial coordinate system (m).
XT	Argument	Target 1 location, X coordinate (m).
Y	Argument	Missile location, Y coordinate, inertial coordinate system (m).
YT	Argument	Target 1 location, Y coordinate (m).
Z	Argument	Missile location, Z coordinate, inertial coordinate system (m).
ZT	Argument	Target 1 location, Z coordinate (m).

TABLE 2.8-7b. Subroutine ATJREF–Output Data.

Name	Source	Description
CMDMR	Common ECMATJ	Decoy-to-missile range (m).
CMDMX	Common ECMATJ	Decoy-to-missile range, X component (m).
CMDMY	Common ECMATJ	Decoy-to-missile range, Y component (m).
CMDMZ	Common ECMATJ	Decoy-to-missile range, Z component (m).
CMDPA	Common ECMATJ	Decoy azimuth angle from target (radians).
CMDPE	Common ECMATJ	Decoy elevation angle from target (radians).
CMDPX	Common ECMATJ	Decoy position, X coordinate (EFCS) (m).
CMDPXO(-)	Common ECMATJ	Last decoy position, X coordinate (EFCS) (m). Dimensioned 4.
CMDPY	Common ECMATJ	Decoy position, Y coordinate (EFCS) (m).
CMDPYO(-)	Common ECMATJ	Last decoy position, Y coordinate (EFCS) (m). Dimensioned 4.
CMDPZ	Common ECMATJ, Return from GETTTD	Decoy position, X coordinate (EFCS) (m).
CMDPZO(-)	Common ECMATJ	Last decoy position, Z coordinate (EFCS) (m). Dimensioned 4.
CMDTX	Common ECMATJ	Decoy-to-target range, X component (m).
CMDTY	Common ECMATJ	Decoy-to-target range, Y component (m).
CMDTZ	Common ECMATJ	Decoy-to-target range, Z component (m).
CMTDR	Common ECMATJ	Target-to-decoy range (m).
ITRTYP	Argument, Return from GETTTD	ATJ terrain type indicator.

TABLE 2.8-8a. Subroutine ATJBOR–Input Data.

Name	Source	Description
APOYNT	Argument	Azimuth pointing angle (yaw) with respect to aircraft, body coordinates (radians).
CMTDR	Argument	Target-to-decoy range (m).
CMDTX	Argument	Decoy-to-target range, X component (m).
CMDTY	Argument	Decoy-to-target range, Y component (m).
CMDTZ	Argument	Decoy-to-target range, Z component (m).
EPOYNT	Argument	Elevation pointing angle (pitch) with respect to aircraft, body coordinates (radians).
PHIT	Argument	Target roll angle (Euler angle of orientation phi) (radians).
PSIT	Argument	Target yaw angle (heading) (Euler angle of orientation psi) (radians).
THETAT	Argument	Target pitch angle (Euler angle of orientation theta) (radians).
XAD	Return from GYRATE	Decoy position in antenna coordinate system, X coordinate (m).
XBD	Return from GYRATE	Decoy position in body coordinate system, X coordinate (m).
YAD	Return from GYRATE	Decoy position in antenna coordinate system, Y coordinate (m).
YBD	Return from GYRATE	Decoy position in body coordinate system, Y coordinate (m).
ZAD	Return from GYRATE	Decoy position in antenna coordinate system, Z coordinate (m).
ZBD	Return from GYRATE	Decoy position in body coordinate system, Z coordinate (m).

TABLE 2.8-8b. Subroutine ATJBOR–Output Data.

Name	Source	Description
CMDAA	Argument	Decoy angle from jammer antenna, azimuth (radians).
CMDAE	Argument	Decoy angle from jammer antenna, elevation (radians).

TABLE 2.8-9a. Subroutine ATJMPI–Input Data.

Name	Source	Description
CMDAA	Argument	Decoy angle from jammer antenna, azimuth (radians).
CMDAE	Argument	Decoy angle from jammer antenna, elevation (radians).
CMDMR	Common ECMATJ	Decoy-to-missile range (m).
CMJALF	Common ECMATJ	Jammer loss factor (magnitude).
CMTDR	Common ECMATJ	Target-to-decoy range (m).
ECMT(-)	Argument	Antenna(s) gain table (1-dimensional array). (Calling subroutine ATJCON passes this argument, which is the array ECMT, of length LECMT (=5000), in common ECMD.)
IPTR	Argument	Pointer to start of gain table for antenna.
ITLU1	Argument	Pointer for subroutine TLU2 (index of last-used X table value).
ITLU2	Argument	Pointer for subroutine TLU2 (index of last-used Y table value).
PIX4	PARAMETER Include CONST	Pi multiplied by 4.
POWER	Argument	Power of jamming technique.

TABLE 2.8-9a. Subroutine ATJMPI–Input Data. (Contd.)

Name	Source	Description
R2D	PARAMETER Include CONST	Radians-to-degrees conversion factor.
ZO	Return from TLU2	Jammer antenna gain from table lookup in ECMT (dB).

TABLE 2.8-9b. Subroutine ATJMPI–Output Data.

Name	Source	Description
CMTPI	Common ECMATJ	Upper limit of reflected power on seeker (watts).

TABLE 2.8-10a. Subroutine ATJFRC–Input Data.

Name	Source	Description
CMCDC	Argument	Terrain complex dielectric constant.
CMDPE	Common ECMATJ	Decoy elevation angle from target (radians).
PIO2	PARAMETER Include CONST	Pi divided by 2.

TABLE 2.8-10b. Subroutine ATJFRC–Output Data.

Name	Source	Description
CMFRC	Common ECMATJ	Fresnel reflection coefficient.

TABLE 2.8-11a. Subroutine ATJRSC–Input Data.

Name	Source	Description
CMDPE	Common ECMATJ	Decoy elevation angle from target (radians).
CMGR	Argument	Terrain RMS height (m).
PIX4	PARAMETER Include CONST	Pi multiplied by 4.
WAVLEN	Argument	Wavelength of ground radar transmitter (m).

TABLE 2.8-11b. Subroutine ATJRSC–Output Data.

Name	Source	Description
CMRSC	Common ECMATJ	Rayleigh scattering coefficient.

TABLE 2.8-12a. Subroutine ATJSDC–Input Data.

Name	Source	Description
CMCL	Argument	Terrain correlation length (m).
CMDPE	Common ECMATJ	Decoy elevation angle from target (radians).
CMGR	Argument	Terrain RMS height (m).
PSI2	Common ECMATJ	Constant for subroutine ATJSDC.
SBW12	Common ECMATJ	Seeker beamwidth-squared in direction 1 (radians squared).
SBW22	Common ECMATJ	Seeker beamwidth-squared in direction 2 (radians squared).
SDC1	Common ECMATJ	Constant for subroutine ATJSDC.
SDC2	Common ECMATJ	Constant for subroutine ATJSDC.
THETA2	Common ECMATJ	Constant for subroutine ATJSDC.
XSQRT2	Common ECMATJ	Square root of 2.
Z	Argument	Missile location, Z coordinate, inertial coordinate system (m).
ZT	Argument	Target 1 location, Z coordinate (m).

TABLE 2.8-12b. Subroutine ATJSDC–Output Data.

Name	Source	Description
GN	Common ECMATJ	Spatial distribution coefficient.

TABLE 2.8-13a. Subroutine ATJSIG–Input Data.

Name	Source	Description
CMARP	Common ECMATJ	Power incident on seeker (w).
CMDMR	Common ECMATJ	Decoy-to-missile range (m).
CMDMX	Common ECMATJ	Decoy-to-missile range, X component (m).
CMDMY	Common ECMATJ	Decoy-to-missile range, Y component (m).
CMDMZ	Common ECMATJ	Decoy-to-missile range, Z component (m).
CMTDR	Common ECMATJ	Target-to-decoy range (m).
GDIFAZ	Return from FEND	Difference pattern in azimuth.
GDIFEL	Return from FEND	Difference pattern in elevation.
GSUM	Return from FEND	Sum of gains of four beams.
IRADFL	Argument	Radar type indicator (1=acquisition, 2=tracker, 3=seeker, 4=illuminator).
PHDLYM	Common ECMATJ	Jammer phase delay (m).
PIX4	PARAMETER Include CONST	Pi multiplied by 4.
RTS	Argument	Range from target to site.
SLOSS	Argument	Seeker antenna loss factor.
WAVLEN	Argument	TTR/seeker/illuminator wavelength (m).

TABLE 2.8-13b. Subroutine ATJSIG–Output Data.

Name	Source	Description
DF1DCY	Argument	Azimuth difference voltage (v).
DF2DCY	Argument	Elevation difference voltage (v).
SUMDCY	Argument	Sum channel voltage (v).

TABLE 2.8-14a. Subroutine ATJDGP–Input Data.

Name	Source	Description
CMDMR	Common ECMATJ	Decoy-to-missile range (m).
CMDMX	Common ECMATJ	Decoy-to-missile range, X component (m).
CMDMY	Common ECMATJ	Decoy-to-missile range, Y component (m).
CMDMZ	Common ECMATJ	Decoy-to-missile range, Z component (m).
CMDPX	Common ECMATJ	Decoy position, X coordinate (EFCS) (m).
CMDPXO(-)	Common ECMATJ	Last decoy position, X coordinate (EFCS) (m). Dimensioned 4.
CMDPY	Common ECMATJ	Decoy position, Y coordinate (EFCS) (m).
CMDPYO(-)	Common ECMATJ	Last decoy position, Y coordinate (EFCS) (m). Dimensioned 4.
CMDPZ	Common ECMATJ	Decoy position, X coordinate (EFCS) (m).
CMDPZO(-)	Common ECMATJ	Last decoy position, Z coordinate (EFCS) (m). Dimensioned 4.
CMDTX	Common ECMATJ	Decoy-to-target range, X component (m).
CMDTY	Common ECMATJ	Decoy-to-target range, Y component (m).
CMDTZ	Common ECMATJ	Decoy-to-target range, Z component (m).
CMTDR	Common ECMATJ	Target-to-decoy range (m).
DOPPLR	Argument	Doppler frequency (Hz).
DT	Argument	Time step size (sec).
IRADFL	Argument	Radar type indicator (1=acquisition, 2=tracker, 3=seeker, 4=illuminator).
WAVLEN	Argument	Seeker wavelength (m).
XDOT	Argument	Missile velocity, X component (m/sec).
XTDOT	Argument	Target 1 velocity, X component (m/sec).
YDOT	Argument	Missile velocity, Y component (m/sec).
YTDOT	Argument	Target 1 velocity, Y component (m/sec).
ZDOT	Argument	Missile velocity, Z component (m/sec).
ZTDOT	Argument	Target 1 velocity, Z component (m/sec).

TABLE 2.8-14b. Subroutine ATJDGP–Output Data.

Name	Source	Description
CMDDF	Argument	Missile-decoy Doppler frequency (Hz).

TABLE 2.8-15a. Subroutine ATJCON–Input Data.

Name	Source	Description
APOYNT	Argument	Azimuth pointing angle (yaw) with respect to aircraft, body coordinates (radians).
CLINTV(-,-)	Common MULC	Array of time intervals between multipath and clutter updates (sec). Dimensioned NUMCL (=3) by MRADFL (=4).
CMCDC	Common ECMD	Terrain complex dielectric constants.
CMCL	Common ECMD	Terrain correlation length (m).
CMDDF	Common ECMV	Missile-decoy Doppler frequency (Hz).
CMDMR	Common ECMATJ	Decoy-to-missile range (m).
CMDPX	Common ECMATJ	Decoy position, X coordinate (EFCS) (m).
CMDPY	Common ECMATJ	Decoy position, Y coordinate (EFCS) (m).
CMDPZ	Common ECMATJ	Decoy position, X coordinate (EFCS) (m).
CMDTX	Common ECMATJ	Decoy-to-target range, X component (m).
CMDTY	Common ECMATJ	Decoy-to-target range, Y component (m).
CMDTZ	Common ECMATJ	Decoy-to-target range, Z component (m).
CMFRC	Common ECMATJ	Fresnel reflection coefficient.
CMGR	Common ECMD	Terrain RMS height (m).
CMRSC	Common ECMATJ	Rayleigh scattering coefficient.
CMTDR	Common ECMATJ	Target-to-decoy range (m).
CMTPI	Common ECMATJ	Upper limit of reflected power on seeker (watts).
DOPPLR	Argument	Doppler frequency (Hz).
DTR	PARAMETER Include CONST	Degrees-to-radians conversion factor.
ECMT(-)	Common ECMD	Jammer antenna(s) gain table (1-dimensional array). Dimensioned LECMT (=5000).
EPOYNT	Argument	Elevation pointing angle (pitch) with respect to aircraft, body coordinates (radians).
FTIME	Common MISSIL	Missile flight time (sec).
GDT	Common GRADAR	Simulation time step or system time increment (sec).
GN	Common ECMATJ	Spatial distribution coefficient.
IANTEN	Argument	Active antenna index.
ILUMR	PARAMETER Include ARYBND	Index pointer for referencing the illuminator radar.
IPANT	Common ECMI	ATJ jammer antenna table pointer.
IRADFL	Common FLAGS	Radar type indicator (1=acquisition, 2=tracker, 3=seeker, 4=illuminator).
ISEKR	PARAMETER Include ARYBND	Index pointer for referencing the seeker radar.
ITERSW	Common TERNDR	Terrain selection flag.
ITRTYP	Common ECMI	Terrain type indicator.
ITTYPE	Common TERNDR	Terrain default type indicator.
LUATJ1	Common TLUPT	Table index for computing upper limit of power impinging on missile (index of last-used X table value).
LUATJ2	Common TLUPT	Table index for computing upper limit of power impinging on missile (index of last-used Y table value).

TABLE 2.8-15a. Subroutine ATJCON–Input Data. (Contd.)

Name	Source	Description
NUMPRO	Common SIGNLI	Number of signals in signal processor.
PHIT	Common TARG	Target roll angle (Euler angle of orientation phi) (radians).
POWER	Argument	Power of jamming technique.
PSIT	Common TARG	Target yaw angle (heading) (Euler angle of orientation psi) (radians).
PWIDTH	Argument	Jammer pulse width (same as that of target).
RTS	Common RELSIT	Range from target to site (m).
SBW12	Common ECMATJ	Seeker beamwidth-squared in direction 1 (radians squared).
SBW22	Common ECMATJ	Seeker beamwidth-squared in direction 2 (radians squared).
TBW1D	Common ECMD	Jammer antenna 3 dB beamwidth-azimuth (degrees).
TBW2D	Common ECMD	Jammer antenna 3 dB beamwidth-elevation (degrees).
TDEL	Argument	Range equivalent for time delay (m).
TERZ	Common PROGC	Default terrain height (m).
THETAT	Common TARG	Target pitch angle (Euler angle of orientation theta) (radians).
WVLTX	Common GRADAR	Wavelength of ground radar transmitter (m).
X	Common MISSIL	Missile location, X coordinate, inertial coordinate system (m).
XDOT	Common MISSIL	Missile velocity, X component (m/sec).
XLOSS	Common GRADAR	Correction loss factor.
XSJ	Common RUNVR	Current site location, X coordinate (m).
XT	Common TARG	Target 1 location, X coordinate (m).
XTDOT	Common TARG	Target 1 velocity, X component (m/sec).
Y	Common MISSIL	Missile location, Y coordinate, inertial coordinate system (m).
YDOT	Common MISSIL	Missile velocity, Y component (m/sec).
YSJ	Common RUNVR	Current site location, Y coordinate (m).
YT	Common TARG	Target 1 location, Y coordinate (m).
YTDOT	Common TARG	Target 1 velocity, Y component (m/sec).
Z	Common MISSIL	Missile location, Z coordinate, inertial coordinate system (m).
ZDOT	Common MISSIL	Missile velocity, Z component (m/sec).
ZSJ	Common RUNVR	TTR antenna location, Z coordinate, inertial coordinate system (m).
ZT	Common TARG	Target 1 location, Z coordinate (m).
ZTDOT	Common TARG	Target 1 velocity, Z component (m/sec).

TABLE 2.8-15b. Subroutine ATJCON–Output Data.

Name	Source	Description
CMARP	Common ECMATJ	Power incident on seeker (w).
CMDAA	Common ECMATJ	Decoy angle from jammer antenna, azimuth (radians).
CMDAE	Common ECMATJ	Decoy angle from jammer antenna, elevation (radians).
CMDDF	Common ECMV	Missile-decoy Doppler frequency (Hz).
CMDPXO(-)	Common ECMATJ	Last decoy position, X coordinate (EFCS) (m). Dimensioned 4.
CMDPYO(-)	Common ECMATJ	Last decoy position, Y coordinate (EFCS) (m). Dimensioned 4.
CMDPZO(-)	Common ECMATJ	Last decoy position, Z coordinate (EFCS) (m). Dimensioned 4.

TABLE 2.8-15b. Subroutine ATJCON–Output Data. (Contd.)

Name	Source	Description
IDBUS(-)	Argument	Array (1-dimensional) of signal ID values.
ITRTYP	Common ECMI	Terrain type indicator.
NUMPRO	Argument	Number of signals in signal processor.
PSI2	Common ECMATJ	Constant for subroutine ATJSDC.
RTSI(-)	Argument	Array (1-dimensional) of ranges of signals.
SDC1	Common ECMATJ	Constant for subroutine ATJSDC.
SDC2	Common ECMATJ	Constant for subroutine ATJSDC.
SGDOP(-)	Argument	Array (1-dimensional) of signal Doppler shifts.
SGDVA(-)	Argument	Array (1-dimensional) of signal azimuth channel voltages.
SGDVE(-)	Argument	Array (1-dimensional) of signal elevation channel voltages.
SGPCBW(-)	Argument	Array (1-dimensional) of pulse compression bandwidths.
SGPW(-)	Argument	Array (1-dimensional) of pulse widths of signals.
SGSV(-)	Argument	Array (1-dimensional) of sum channel voltages.
TBW1	Common ECMATJ	Jammer antenna 3 dB beamwidth-azimuth (radians).
TBW2	Common ECMATJ	Jammer antenna 3 dB beamwidth-elevation (radians).
THETA2	Common ECMATJ	Constant for subroutine ATJSDC.

2.8.4 ASSUMPTIONS AND LIMITATIONS

The on-board deceptive ECM is played in a generally realistic manner. For the ground radar, it is possible that the operator could take some different actions if deceptive jamming were detected. One option would be to change to optical tracking. Since ESAMS 2.7 does not model the human operator in an integrated fashion, the ESAMS user should run some excursions, such as the optical track mode, to bound the impact due to the man-in-the-loop.

ESAMS 2.7 has a number of ECCM techniques which may be employed by the missile seeker. These will be covered in the tracking VSDs. The impact of the ECCM techniques against the missile seeker should also be bounded through parametric studies.